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THE PRESENCE OF SOME BENZENE DERIVATIVES IN SOILS

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INTRODUCTION

The isolation of organic compounds from soils may have an interest other than that of the purely scientific nature attached to any increase in our knowledge of the composition of soils. This is true, not only when the compounds are known to be readily reactive with other compounds or to have an effect on the microflora of the soil or the growth of higher plants, but also when their constitution indicates that they may have such an effect. Recently three organic compounds have been isolated from soils that seem to be of this nature.

These compounds, rather closely related in constitution, are benzoic acid, metaoxytoluic acid, and vanillin. They were obtained from samples of sandy soil from Florida at present devoted to orange culture. These soils are composed of quartz sand ranging in color from light gray to brown and contain very little organic matter. For the most part this organic matter is deposited in a thin layer on the grains of sand, so that when the soils are treated with dilute alkali and the film of organic material is thereby dissolved or loosened pure white quartz sand remains. The samples, about 90 kilograms in each case, were from eight locations, the top soil and subsoil being represented by separate samples.

BENZOIC ACID

Benzoic acid was obtained from but one of these samples—a subsoil. There was no indication of its presence in the corresponding surface soil, and, although indications were obtained of its presence in other subsoils of this series, it could not be isolated in a pure form in sufficient quantity for identification.

The method by which benzoic acid was obtained from this soil was as follows:

The soil was treated at room temperature with a 2 per cent solution of sodium hydroxid for six hours, allowed to stand several hours, and the

colored extract siphoned off. This extract was acidified with sulphuric acid, filtered, and the acid filtrate shaken out several times with ether. The ether extracts were combined and the ether evaporated on the surface of a small quantity of warm water. The water was then heated to boiling and filtered hot, when, on cooling the filtrate, crystals separated. A further yield of crystals was obtained on concentrating the mother liquor from the crystals first obtained. The compound obtained in this way was purified by recrystallizing from water, and finally by sublimation, when a pure white product was obtained. About 2 grams were obtained from 25 kilograms of soil.

This compound had all the properties of benzoic acid. It crystallized in the leaflets characteristic of benzoic acid. It was readily soluble in alcohol, ether, and chloroform, sparingly soluble in cold water but much more readily in hot water, and melted at 121° C. An aqueous solution was acid in reaction, and when neutralized and treated with a neutral solution of ferric chlorid a dirty-brown precipitate was formed that was insoluble in acetic acid. The compound sublimed readily and when heated strongly gave off the irritating fumes characteristic of benzoic acid when so treated. Finally it gave Mohler's reaction.[1]

The appearance and properties of the compound obtained from the soil, its behavior with ferric chlorid, and response to Mohler's test are sufficient to establish its identity as benzoic acid.

METAOXYTOLUIC ACID

Metaoxytoluic acid was obtained from several samples of the series examined, but in quantity only from subsoils. The method by which it was obtained was exactly the same as that just outlined for benzoic acid up to the point of obtaining a water solution of the ether extract. If no benzoic acid or other compound separated on cooling the filtrate, it was concentrated nearly to dryness and allowed to stand, when oxytoluic acid, if present, crystallized out. The compound so obtained was purified by repeated recrystallizations from water and was finally dried on a porous plate. This product retained persistently a slight tinge of color, and it was only after many treatments and much loss of material that it could be freed from color. Where traces of benzoic acid accompanied it, as seemed to be the case in some instances, it could be freed from benzoic acid by sublimation, this acid being much more readily sublimed than oxytoluic acid. About 10 grams of pure material were obtained from 25 kilograms of soil.

[1] Mohler's test is carried out by heating the substance to be determined with sulphuric acid until charring takes place, sulphobenzoic acid being formed if benzoic acid is present in the original material. On treating with potassium nitrate this will be transformed into metadinitro-benzoic acid. On adding excess of ammonia to this acid and then a few drops of a colorless solution of ammonium sulphid a red color will be obtained.

Official and provisional methods of analysis, Association of Official Agricultural Chemists. U. S. Dept. Agr. Bur. Chem. Bul. 107 (rev.), p. 181, 1908.

Mohler, E. Recherche de l'acide benzoïque dans les substances alimentaires. Bul. Soc. Chim., Paris, s. 3, t. 3, p. 414-416, 1890.

On elementary analysis this compound gave the following results (0.200 gram were used for each analysis):

	Analysis 1. *Per cent.*	Analysis 2. *Per cent.*
Carbon	63.33	63.02
Hydrogen	5.39	5.66
Oxygen	31.28	31.32

This corresponds with the composition of oxytoluic acid, $C_8H_8O_3$, which contains 63.15 per cent of carbon, 5.26 per cent of hydrogen, and 31.50 per cent of oxygen. There are 10 isomeric oxytoluic acids, all of which have been described. The compound obtained from the soil has the properties of metaoxytoluic acid, with the carboxyl, hydroxyl, and methyl radicals in the 1. 3. 5. positions, respectively.

This compound crystallizes in plates or, when the quantity is small, in groups of radiating needles. It is rather soluble in cold water, but more so in hot water. It is soluble in alcohol and ether, sublimes unchanged, and melts at 208° C. On the addition of a solution of ferric chlorid, an aqueous solution of the compound gives a brown precipitate which dissolves to a brown solution when the reagent is added in excess. On the distillation of the dry compound with lime, metacresol is formed. The identity of the metacresol obtained from the soil compound in this way was established by transforming it into 2. 4. 6. trinitrocresol, a yellow compound melting at 106° to 107° C. This was effected by dissolving the metacresol in strong sulphuric acid, pouring into a mixture of nitric and sulphuric acids, heating, and then cooling. The nitro product was filtered off, washed with dilute hydrochloric acid, recrystallized, and dried.

Metaoxytoluic acid was made from sulphotoluic acid according to the method of Jacobsen,[1] and its properties were compared with the compound obtained from the soil, the two agreeing in every respect. When the artificial product and the soil compound were mixed, the melting point was unchanged. The agreement in composition and properties mentioned is sufficient to establish the identity of the compound obtained from the soil as metaoxytoluic acid.

VANILLIN

In the course of investigations of the organic matter of soils carried on for the past six years soil extracts having the odor of vanillin and giving some of the reactions of that compound have been encountered from time to time, but its presence could not be confirmed by isolation in pure form. In investigating the soil samples from Florida the isolation was accomplished.

The method of isolation, as with the compounds just described, was begun by making an alkaline extract of the soil. This extract was acidified and filtered and was then shaken out with several portions of ether.

[1] Jacobsen, Oscar. Oxytoluylsäuren und Oxyphtalsäuren. Ber. Deut. Chem. Gesell., Jahrg. 14, Juli-Dez., p. 2357–2359, 1881.

The combined ether extracts were shaken with a strong solution of sodium bisulphite, which treatment removes from the ether compounds of an aldehyde nature. After separating the bisulphite from the ether it was acidified with enough sulphuric acid to decompose all the bisulphite, was freed from sulphur dioxid by blowing air through it, and was again shaken with ether. On evaporating the ether extract at room temperature a more or less oily, viscous residue remained which had the odor of vanillin and gave the reactions of that compound. Crystals usually separated from this residue after standing several days.

When these crystals were obtained in sufficient quantity, they were purified by the method recommended for the examination of vanilla extracts.[1] The oily residue was treated several times with warm water and filtered, and the filtrate treated with a solution of lead acetate as long as a precipitate formed, and was then again filtered. The filtrate was shaken out several times with ether, and the combined ether extracts were evaporated. The residue usually crystallized readily, although it still contained traces of resinous matter. This resinous material could not be removed by taking up in ammonia, acidifying, and again shaking with ether as recommended in the method for vanilla extracts, but by recrystallizing from water several times and finally drying on a porous plate pure crystals were obtained.

These crystals had a strong odor of vanilla, were in the form of needles or small prisms, and melted at 80° to 81° C., the melting point of vanillin. They were readily soluble in ether or alcohol, but were sparingly soluble in water. An aqueous solution gave the following reactions characteristic of vanillin or the group of compounds to which vanillin belongs:

The addition of a solution of ferric chlorid gave a blue-violet color. Colors ranging from blue to violet are given by many hydroxy-benzene compounds.

When boiled with resorcinol and hydrochloric acid, a red color was formed. This reaction is given by a number of aldehydes, including some sugars.

When the crystals were treated with equal quantities of sulphuric and hydrochloric acids and with the addition of a drop of a dilute solution of acetone and the mixture then heated to 100° C. for 15 minutes, a violet color was developed.

On adding an excess of bromin water followed by the addition of ferrous sulphate, a blue-green color was formed. This reaction is regarded as characteristic of vanillin, but does not seem applicable for colorimetric determination.

When the reagent of Folin and Denis [2] was added and the mixture made alkaline with an excess of sodium carbonate, a clear blue color was

[1] Official and provisional methods of analysis, Association of Official Agricultural Chemists. U. S. Dept. Agr. Bur. Chem. Bul. 107 (rev.), p. 156, 1908.

[2] Folin, Otto, and Denis, W. On phosphotungstic-phosphomolybdic compounds as color reagents. Jour. Biol. Chem., v. 12, no. 2, pp. 239-243, 1912.

slowly developed. This reaches a maximum in a short time and remains constant for several hours, furnishing a reliable colorimetric method for the determination of vanillin.[1]

The method of isolating the compound from the soil, its crystalline form, odor, melting point, and the fact that it gave the characteristic reactions of vanillin are sufficient to establish its identity as vanillin.

The quantity of pure vanillin obtained by this method from any of the soils examined was but a few milligrams from 25 kilograms. It was possible to obtain the vanillin in pure crystalline form from 4 of the 16 samples. From some of the other samples crystals were obtained that gave the reactions of vanillin, but there were not enough for the separation and determination of the melting point. Residues were obtained from all the samples having the odor of vanillin and giving two or more reactions for it. In each case where it was possible to separate vanillin in pure form the sample was a surface soil.

An application of the colorimetric method of Folin and Denis was made to two samples, those from which the most vanillin had been obtained by alkaline extraction. One hundred grams of soil were finely ground and thoroughly extracted with warm alcohol that had been freshly distilled. The alcohol was evaporated, and the residue was taken up with warm water and filtered. Lead acetate was added to the filtrate as long as a precipitate formed. The solution was then filtered and the filtrate treated with the reagent of Folin and Denis (a mixture of phosphotungstic and phosphomolybdic acids), followed by an excess of sodium carbonate. It was again filtered and made to a definite volume. The resulting blue solution was read in a colorimeter against a solution prepared in the same way from a standard solution of vanillin. Sample No. 1 gave 0.0010 per cent of vanillin, or 10 parts per million, while sample No. 2 showed 0.00048 per cent, or 4.8 parts per million.

Vanillin contains the radical methoxyl OCH_3. In a previous paper[2] it was shown that the methoxyl radical is present in many soils in sufficient quantity to be determined by the Zeisel method.[3] A determination of the methoxyl in samples Nos. 1 and 2 by this method gave, for sample No. 1, 0.065 per cent of methoxyl calculated to vanillin, and for sample No. 2, 0.050 per cent.

Methoxyl is contained in a number of organic compounds and is a constant constituent of the lignocellulose of plants. The quantity obtained from these soils when calculated to vanillin is so much in excess of that actually obtained in the isolation from an alkaline extract, or that

[1] Folin, Otto, and Denis, W. A new colorimetric method for the determination of vanillin in flavoring extracts. Jour. Indus. and Engin. Chem., v. 4, no. 9, pp. 670–672, 1912.

[2] Shorey, E. C., and Lathrop, E. C. Methoxyl in soil organic matter. Jour. Amer. Chem. Soc., v. 33, no. 1, p. 75–78, 1911.

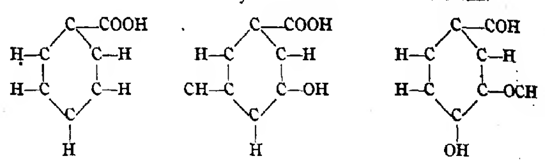
[3] Zeisel, S. Über ein Verfahren zum quantitativen Nachweise von Methoxyl. Monatsh. Chem., Bd. 6, 1885, p. 989–996, 1 pl. 1886.

—— Zum quantitativen Nachweise von Methoxyl. Monatsh. Chem., Bd. 7, 1886, p. 406, 409. 1887.

indicated by the Folin-Denis method, that it seems evident that a considerable portion of it must be derived from compounds other than vanillin.

These three compounds, benzoic acid, metaoxytoluic acid, and vanillin, although not related in the sense that they are readily derived from or transformed into one another, are related as shown by the following structural formulas:

Benzoic acid. Metaoxytoluic acid. Vanillin.



Benzoic acid is a naturally occurring product obtained from certain gums and balsams, wherein it exists as an ester. It is also present in some fruits, such as plums and cranberries, and has been found among the oxidation products of casein and gelatin. Its presence in soil might then result from the decay of plant tissues containing it or from oxidation of more complex compounds through the activity of microorganisms. The most remarkable fact in connection with its occurrence in the soils examined is that it was found in appreciable quantity in but one sample, although they were of the same general character. In the absence of accurate information regarding previous natural vegetation on these soils and other data that can be obtained only in the field, any attempt to explain this fact is out of place here.

Metaoxytoluic acid, so far as known, is not a natural product, and its method of preparation in the laboratory does not suggest any process by which it might be formed in the soil from plant products or other compounds known to occur in soils.

Vanillin has its chief natural source in the so-called vanilla beans, or seed pods, of *Vanilla pompona*. It has also been reported as found in small quantities in a number of other plants or plant products, and it probably is more widely distributed in the vegetable kingdom than has been supposed. At present there is no information indicating its formation from other compounds through the agency of microorganisms, and the small quantity found in soils may possibly be regarded as an unchanged residue of plant débris.

Using the maximum figures for quantities obtained in these investigations and calculating to the acre-foot of soil, the following approximate quantities are obtained: Benzoic acid, 350 pounds; metaoxytoluic acid, 800 pounds; and vanillin, 40 pounds to the acre-foot.

In the case of the two acids the method involved considerable loss of material and the actual quantity present in the soil is undoubtedly in excess of these figures.

The question as to the form in which these compounds exist in the soil is one deserving some consideration, although one not easily answered satisfactorily. It is true of most organic compounds that have been obtained from soils through extraction with dilute alkali that they are not readily obtained as such by water extraction of the soil. In many soils this can be explained, in part at least, by the fact that much of the organic matter in soils is of a resinous nature wholly insoluble in water, and compounds which when separated are easily soluble in water are so incased or protected by the resinous or varnishlike coating effected by this resinous material that they are very slowly dissolved, if at all, when the soil is leached. This effect is quite apart from any absorptive effect and is quite marked in extreme types, such as the sands of Florida and some peats, where either fine grinding or previous treatment with alcohol will render soluble in water organic material that before this treatment was so little soluble as to escape notice.

In the case of vanillin, grinding the soil and extracting with alcohol gave more of the compound than was obtained by extraction with alkali, and from the known properties of vanillin it seems unlikely that the quantity found is in the soil in any other form than free vanillin.

Treatment of the soil with hot alcohol after grinding gave extracts from which reactions for both benzoic acid and metaoxytoluic acid could be obtained, but in the absence of colorimetric methods applicable to small quantities and owing to the fact that the extractions with alcohol were made with much smaller quantities of soil than the extraction with sodium hydroxid, no comparative figures can be given. It is fair to conclude, however, that in some of the soils examined some portion of both acids is present as free acid.

INDICATOR SIGNIFICANCE OF VEGETATION IN TOOELE VALLEY, UTAH

By T. H. KEARNEY,[1] L. J. BRIGGS,[2] H. L. SHANTZ,[3] J. W. MCLANE,[4] and R. L. PIEMEISEL,[5]
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INTRODUCTION

In the arid portion of the United States the different types of native vegetation are often very sharply delimited, the transitions being so abrupt that they can not be attributed to climatic factors; this has suggested the possibility of correlating the distribution of the vegetation with the physical and chemical properties of the soil. If such correlations can be made, they may be utilized in the classification of land with respect to its agricultural capabilities.

One of the writers[6] has described the correlations which exist in the Great Plains between the different types of vegetation and the physical characteristics of the corresponding types of land and has pointed out how the native growth may be used in that region to determine the suitability of the land for dry farming.

The results obtained in the Great Plains made it desirable to undertake similar investigations in the Great Basin region, or that portion of the United States lying between the Rocky Mountains on the east and the Sierra Nevada and Cascade Ranges on the west. The problems to be solved were: First, what types of vegetation indicate conditions of soil moisture favorable or unfavorable to dry farming, and, second, what types indicate the presence or absence of alkali salts in quantities likely to injure cultivated crops. For the purpose of this investigation it was necessary to find a locality where both dry farming and irrigation farming are practiced, where much of the land is still covered with the original native growth, and where some of the soils contain an excess of alkali salts.

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[2] Biophysicist in Charge, Biophysical Investigations.
[3] Plant Physiologist, Alkali and Drought Resistant Plant Investigations.
[4] Laboratory Assistant, Biophysical Investigations.
[5] Scientific Assistant, Alkali and Drought Resistant Plant Investigations.
[6] Shantz, H. L. Natural vegetation as an indicator of the capabilities of land for crop production in the Great Plains area. U. S. Dept. Agr., Bur. Plant Indus. Bul. 201, 100 p., 23 fig., 6 pl. 1911.

With the exception of the valuable work of Hilgard in Mississippi and of Hilgard and his associates in California (see Hilgard, E. W., Soils, New York, 1906, p. 487–548, figs. 77–89), very little had previously been done in the United States toward a scientific study of native vegetation from the indicator point of view. In Europe, however, the subject has been much investigated, especially as regards "lime-loving" and "lime-avoiding" plants.

After a reconnoissance trip through portions of Wyoming, Utah, Idaho, and Oregon in August, 1911, the Tooele Valley in central Utah was selected for the following reasons: (1) several very distinct types of vegetation are found within a small area, (2) the soils show a great diversity in their moisture conditions and salt content, (3) the greater part of the area retains its original plant cover, while examples of crop production both with and without irrigation exist on different types of land.

Detailed studies of the vegetation of Tooele Valley in relation to the moisture conditions and salt content of the soil were carried on in 1912. The work was begun near the close of the rainy season (end of May) and was terminated during the first week of August, when the summer drought had reached its height. Additional data were obtained during a third visit to the valley in the latter part of August, 1913.

The distribution of the native vegetation was found to depend in a marked degree upon the physical and chemical properties of the soils, factors which also influence crop production. So far as this particular area is concerned, the vegetation can unquestionably be used with advantage in classifying land with respect to its agricultural value. To what extent the correlations established in Tooele Valley hold good in other parts of the Great Basin region remains to be determined by future investigation.

The writers desire to acknowledge the helpful cooperation of Director E. D. Ball, of the Utah Agricultural Experiment Station, and of Prof. L. A. Merrill, formerly of that station. The writers are indebted for the determination of the plants collected to Mr. Ivar Tidestrom, of the Office of Economic and Systematic Botany, Bureau of Plant Industry.

METHODS OF RESEARCH

The methods used in classifying and describing the types of vegetation are well known to ecological plant geographers and are best described in setting forth the results. Some explanation of the methods used in investigating the moisture conditions and salinity of the soils, however, is desirable.

Samples of the soil were taken in the midst of the areas occupied by each vegetation type. Where the boundaries between two types were well defined, samples were also taken on both sides of the line, in order to determine the limiting conditions for each type. The measurements of moisture content, moisture equivalent, electrical resistance, and salt content which were made upon these samples served as a basis for conclusions regarding the physical conditions indicated by the presence of each important type of vegetation.

COLLECTING SOIL SAMPLES.—The samples of soil were in all cases collected with the aid of a sampling tube, which prevents the admixture of surface material with the subsoil. Each sample consisted of a

composite of four cores. The soils were usually sampled to a depth of 4 feet and occasionally to a greater depth, the cores being taken in 1-foot sections.

Determining the Soil-Moisture Content.—Numbered tin boxes of uniform weight and with tight-fitting covers were used to receive the soil samples directly from the sampling tubes. The whole sample was used as a basis for the moisture determinations and after the initial weighing was dried in a water oven to constant weight. The moisture content is in all cases expressed as a percentage of the dry weight of the sample.

Determining the Moisture Equivalent.—In studying soil moisture in relation to plant growth it is important to have some standard for measurement of the retentivity of the soil for moisture. As two of the authors have previously shown,[1] this may be conveniently accomplished by the method of moisture equivalents. This method consists in subjecting a moist sample of soil to a constant centrifugal force equal to 1,000 times that of gravity until the moisture content of the soil is reduced to the point where it is in equilibrium with the centrifugal force employed. The residual moisture content of the soil is then determined. This value, expressed as a percentage of the dry weight of the sample, is the moisture equivalent. A direct measure of the retentiveness for moisture of the various soils is thus obtained, and, since the same force is employed throughout, all of the determinations are directly comparable.

Determining the Wilting Coefficient.—It has been shown by two of the authors[2] that the moisture equivalent serves as a useful indirect means of determining the wilting coefficient. The latter term designates (as a percentage of the dry weight of the soil) the quantity of water remaining in the volume of soil occupied by the active roots of a plant which is beginning to wilt.[3]

These determinations (moisture equivalent and wilting coefficient) serve to give an idea of the texture of the soils occupied by the different plant associations, as indicated by their retentiveness for moisture. By subtracting the wilting coefficient from the actual moisture content a measure is obtained of the percentage of moisture available for the active growth of plants at the time the soil samples were taken.

Determining the Salt Content.—The total salt content of each soil sample was determined by the electrical-resistance method developed

[1] Briggs, L. J., and McLane, J. W. Moisture equivalents of soils. U. S. Dept. Agr., Bur. Soils Bul. 45, 23 p., 1 fig., 1 pl. 1907.

Briggs, L. J., and McLane, J. W. Moisture-equivalent determinations and their application. Proc. Amer. Soc. Agron., v. 2, 1910, p. 138–147, pl. 6. 1912.

[2] Briggs, L. J., and Shantz, H. L. The wilting coefficient for different plants and its indirect determination. U. S. Dept. Agr., Bur. Plant Indus. Bul. 230, 83 p., 9 fig., 2 pl., 1912.

[3] "Wilting" in this case must be understood as permanent wilting—i. e., a condition from which the plant can not recover its turgidity until the soil receives additional moisture, no matter how great the humidity of the atmosphere.

in the Bureau of Soils.[1] The method is simple and rapid and the measurements can be readily made in the field, which is a great advantage in studying the distribution of vegetation in relation to the salt content of the soil. The method is, however, necessarily an approximate one, owing to the variation in the composition of the soil solution and to the fact that the salts found in soils differ greatly with respect to their molecular weight and ionic migration velocity. To interpret the observed resistance, a calibration curve was prepared, based upon the observed relationship between the electrical resistance and the salt content, gravimetrically determined, of a number of soils from different parts of the valley. (See fig. 1.)

In making the gravimetric determinations, the usual practice was followed of digesting 100 grams of dry soil with 500 c. c. of water, filtering, and evaporating an aliquot

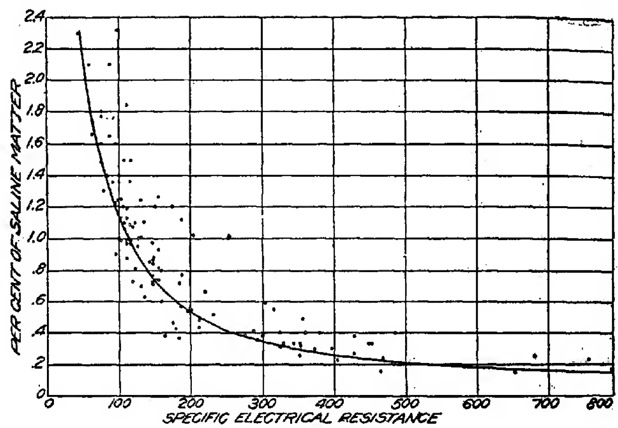


FIG. 1.—Curve showing the relation between the salt content (in percentages of the dry weight of the soil) and the specific electrical resistance (in ohms) of the soil when saturated with water.

portion of the filtrate to dryness. A number of the samples examined were rich in gypsum, and in digesting such soils with an excess of water the total quantity of gypsum which goes into solution is greatly in excess of the quantity dissolved when the soil is simply saturated with water. The gravimetric determination of the salt content of soils which are rich in gypsum is consequently too high, and this accounts in part at least for the outlying points above the calibration curve. (Fig. 1.)

By means of a suitable centrifugal apparatus it is possible to remove and collect a portion of the soil solution in an unsaturated soil. From the concentration of this solution and the initial moisture content of the soil, the salt content of the soil can be calculated. This method gave results more nearly in accord with those indicated by

[1] Whitney, Milton, and Means, T. H. An electrical method of determining the soluble salt content of soils. U. S. Dept. Agr., Div. Soils Bul. 8, 30 p., 6 fig. 1897.

Briggs, L. J. Electrical instruments for determining the moisture, temperature, and soluble salt content of soils. U. S. Dept. Agr., Div. Soils Bul. 15, 35 p., 12 fig. 1899.

Davis, R. O. E., and Bryan, H. The electrical bridge for the determination of soluble salts in soils. U. S. Dept. Agr., Bur. Soils Bul. 61, 36 p., 7 fig. 2 pl. 1910.

the electrical resistance. Therefore, in the case of soils containing gypsum the electrical-resistance method may be considered to be more reliable than the excess-solvent method. The probable error of determinations by the electrical-resistance method is approximately 10 per cent of the actual salt content.

CLIMATE OF TOOELE VALLEY

Tooele Valley is dry, having a mean annual precipitation of 16 inches.[1] The average monthly distribution of the precipitation at Tooele is shown in figure 2. No precipitation records are available for other parts of the valley, save fragmentary records at Grantsville for two years, which indicate that the western side of the valley receives decidedly less precipitation than the eastern slope. During the first nine months of 1912, the total precipitation recorded at Grantsville was 7.6 inches, as compared with 13 inches at Tooele. The condition of the native vegetation and of the crops grown without irrigation also indicates that the western side of the valley is much drier than the eastern side.

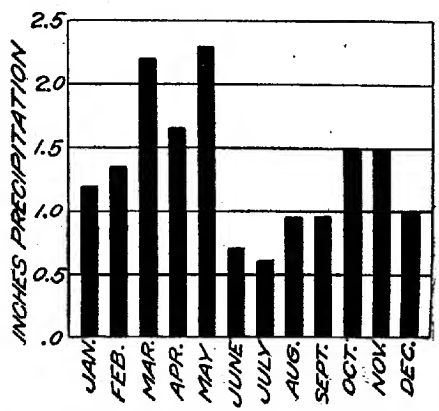


FIG. 2.—Monthly distribution of precipitation at Tooele, Utah (mean for 15 years).

In view of the importance of the soil-moisture conditions in explaining the distribution of the different types of vegetation in Tooele Valley, it is interesting to consider the precipitation of the period immediately prior to that during which the field work was carried on. The precipitation during the months from October to May, inclusive, probably furnishes all of the stored soil moisture available for the growth of plants during the following summer. The total precipitation at Tooele during the period from October, 1911, to May, 1912, was 13.5 inches, or 0.9 inch above the normal (12.6 inches) for the locality. Hence, it may be assumed that at least the normal quantity of moisture was present in the soil on the date when field operations were begun in the valley (May 28). As regards the season of active growth in 1912, the precipitation of the month of May was about 0.5 inch below the normal for Tooele, while that of June was very nearly twice the normal. For the remaining summer months the precipitation was about normal.

[1] Based upon 15 years' measurements at the town of Tooele. From data furnished by the U. S. Weather Bureau, through the courtesy of Mr. A. H. Thiessen, Section Director.

While no evaporation data are available for Tooele Valley, evaporation measurements[1] have been made during the last five years at Nephi, about 60 miles south of Tooele. These measurements show that the monthly evaporation during June, July, and August is at least double that of April and October. (See Table I.)

TABLE I.—*Evaporation from a free-water surface at Nephi, Utah, during the months of April to October, 1908 to 1912.*

Year.	April.	May.	June.	July.	August.	September.	October.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1908	....	....	7.87	10.52	9.34	6.23	....
1909	3.64	5.99	8.81	9.47	7.03	5.59	4.43
1910	5.82	7.46	10.90	9.98	10.09	6.01	3.72
1911	4.93	8.41	8.69	8.72	10.47	6.69	3.65
1912	3.54	6.30	9.28	9.24	8.89	6.16	2.98
Normal	4.48	7.04	9.11	9.59	9.16	6.14	3.70

Therefore, while the summer months are by no means rainless in this locality, the great increase in the rate of evaporation is such that the light precipitation can have but little effect upon vegetation. In those parts of the valley where the ground water is beyond the reach of the plant roots the vegetation becomes dormant after the moisture stored in the soil by the winter and spring rains has been exhausted. Herbaceous plants ripen and die, at least to the ground, while the woody species, losing much of their foliage and reducing their transpiration to a minimum, enter a resting condition which is nearly as complete as that which is brought about by the low temperatures of winter. Where there is a greater depth of readily permeable soil in which moisture can be stored than is ordinarily the case in this valley, the beginning of summer dormancy is longer postponed. On the sand hills the larger shrubs may continue growing more or less actively throughout the summer. In the lower part of the valley, where the ground-water table is high and the soil is moist throughout the summer nearly or quite to the surface, active growth continues until it is terminated by frosts.

GEOLOGY AND TOPOGRAPHY OF TOOELE VALLEY

Geologically, Tooele Valley is of exceptional interest because of its occupancy at one time by a bay of Lake Bonneville, a Pleistocene lake, the beach lines of which are strikingly in evidence upon the sides of the surrounding mountains. The highest of these terraces is 1,000 feet above the present surface of Great Salt Lake. An exhaustive study of the region has been made by Gilbert.[2]

[1] Measurements by the Office of Biophysical Investigations in cooperation with the Office of Cereal Investigations, Bureau of Plant Industry, and with the Utah Agricultural Experiment Station.

[2] Gilbert, G. K. Lake Bonneville. 438 p., 51 illus., 51 pls. Washington. 1890. (U. S. Geol. Survey Monograph 1.)

Tooele Valley is broadly U-shaped in cross section, the mountains on either side rising somewhat abruptly from the valley floor. This abrupt change from valley plain to mountain is characteristic of many of the valleys of the region and is due to the extensive deposition of alluvium during some epoch prior to the Bonneville period.

Tooele Valley is bounded on the east by the Oquirrh Mountains and on the west by the Stansbury or Aqui Range. The southern boundary is formed by a spur of the Stansbury Range and by the great Stockton embankment, which is composed of sand and water-worn gravel thrown up by the waters of Lake Bonneville and which separates Tooele Valley from Rush Valley. (The Stockton embankment is shown in extreme background of Pl. XLV, fig. 3.) The summit of this embankment coincides with the highest shore line on the adjacent mountains. To the north the valley slopes downward to the southern shore of Great Salt Lake. The axis of the valley thus lies approximately on a north and south line, the land rising gradually from near the center to the mountain ranges on the east and west sides. The width of Tooele Valley at the northern end is about 18 miles, at the southern end it is about 13 miles, and its greatest length is approximately 16 miles. The total area of the valley floor is, roughly, 250 square miles.

The slope of the valley from the sides and from the southern end to a line marked approximately by the highway from Salt Lake City to Grantsville is decidedly steep, as is indicated by the fact that the town of Tooele has an elevation above sea level of 4,900 feet, while Grantsville, although less than 5 miles farther north, is 680 feet lower.[1] North of this line the slope becomes very gentle and the surface of this portion of the valley is plainlike.

SALINE CONDITIONS OF TOOELE VALLEY

The soils of Tooele Valley show a wide range in salinity, or, to use the more familiar term, in "alkali" content. The soils in the upper end of the valley and along the base of the foothills at either side, including a large alluvial fan northeast of the town of Tooele, are characterized by a low salt content. The other extreme is found in the flats adjacent to the lake, which in some cases contain such an excess of soluble salts as to prevent the development of a plant cover. The soils occupying the central portion of the valley are, as a rule, relatively free from salts in the surface foot, but the salinity of the subsoil is usually such as to exclude all deep-rooted plants except those that are salt-tolerant to a marked degree. The saline material in solution in the nearly saturated soils of the flats, like that of the lake itself, is made up largely of sodium chlorid. In fact, these flats have probably not infrequently been submerged by the rise of the lake, since records made by the United States

[1] The elevation of the surface of the water of Great Salt Lake is about 4,200 feet.

Geological Survey show that within the last 40 years the lake has undergone a fluctuation in level of 16 feet.

The following determinations of the composition of the saline material in Great Salt Lake, which are quoted from a compilation by Clarke,[1] are therefore of interest in showing what may be regarded as the typical composition of the saline material in this part of the area.

TABLE II.—*Analyses of water from Great Salt Lake.*[1]

	A	B	C	D	E	F	G	H
Cl	55.99	56.21	55.57	56.54	55.69	55.25	55.11	53.72
Br	Trace.	....	....	....	Trace.	Trace.	....	....
SO_4	6.57	6.89	6.86	5.97	6.52	6.73	6.66	5.95
CO_3	....	.07	....	....	....	....	....	....
Li	Trace.	....	....	....	.01	Trace.	....	....
Na	33.15	33.45	33.17	33.39	32.92	34.65	32.97	32.81
K	1.60	(?)	1.59	1.08	1.70	2.64	3.13	4.99
Ca	.17	.20	.21	.42	1.05	.16	.17	.31
Mg	2.52	3.18	2.60	2.60	2.10	.57	1.96	2.22
(Fe_2O_3, Al_2O_3, SiO_2)	....	....	....	....	.01	....	....	....
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Salinity, per cent	14.994	13.790	15.671	19.558	[1]23.036	27.72	22.99	17.68

[1] More correctly 230.355 grams per liter.

"A. By O. D. Allen, Rept. U. S. Geol. Expl. 40th Par., vol. 2, 1877, p. 433. Water collected in 1869. A trace of boric acid is also reported, in addition to the substances named in the table. Allen also gives analyses of a saline soil from a mud flat near Great Salt Lake. It contained 16.40 per cent of soluble matter much like that of the lake water.

"B. By Charles Smart. *Cited in* Resources and attractions of the Territory of Utah, Omaha, 1879. Analysis made in 1877.

"C. By E. von Cochenhausen, for C. Ochsenius, Zeitschr. Deutsch. geol. Gesell., vol. 34, 1882, p. 359. Sample collected by Ochsenius April 16, 1879. Ochsenius also gives an analysis of the salt manufactured from the water of Great Salt Lake.

"D. By J. E. Talmage, Science, vol. 14, 1889, p. 445. Collected in 1889. An analysis of a sample taken in 1885 is also given.

"E. By E. Waller. School of Mines Quart., vol. 14, 1892, p. 57. A trace of boric acid is also reported.

"F. By W. Blum. Collected in 1904. Recalculated to 100 per cent. Reported by Talmage in Scottish Geog. Mag., vol. 20, 1904, p. 424. An earlier paper by Talmage on the lake is in the same journal, vol. 17, 1901, p. 617.

"G. By W. C. Ebaugh and K. Williams, Chem. Zeitung, vol. 32, 1908, p. 409. Collected in October, 1907.

"H. By W. Macfarlane, Science, vol. 32, 1910, p. 568. Collected in February, 1910. A number of other analyses, complete or incomplete, are cited in this paper by Ebaugh and Macfarlane."

It will appear from these analyses that sodium and chlorin together constitute about 90 per cent of the total soluble material. The quantity of chlorin is, in each analysis, slightly greater than that necessary to satisfy the basic requirements of sodium. The rest of the soluble material is made up almost wholly of potassium, magnesium, and the sulphate radical. Concerning these analyses Clarke[2] says:

> Although the salinity of the lake is very variable and from four to seven times as great as that of the ocean, its saline matter has nearly the same composition. The

[1] Clarke, F. W. Data of geochemistry. U. S. Geol. Survey Bul. 491, ed. 2, p. 144. 1911.

[2] Clarke, F. W. Op. cit.

absence of carbonates, the higher sodium, and the lower magnesium are the most definite variations from the oceanic standard; but the general similarity, the identity of type, is unmistakable. * * *

All the waters tributary to Great Salt Lake, so far as they have been examined, contain notable quantities of carbonates, which are absent from the lake itself. These salts have evidently been precipitated from solution, and evidence of this process is found in beds of oolitic sand, composed mainly of calcium carbonate, which exist at various points along the lake shore. The strong brine of the lake seems to be incapable of holding calcium carbonate in solution.

The analyses as given in Table II report the presence of carbonates in solution in the lake water in only one instance.[1] It is in this respect that the saline matter of the soils more distant from the lake differs most markedly from the type just considered. Calcium carbonate was found widely distributed in the soils of the valley. Sodium carbonate was often found also, usually in small amounts (0.05 to 0.10 per cent of the dry weight of the soil), but occasionally samples were collected containing as high as 0.25 per cent. Sodium carbonate was found most frequently in the samples collected in areas where Kochia was growing. These soils were also highly calcareous. The available data on the distribution of sodium carbonate do not, however, indicate that it can be correlated with the presence of any particular plant community.

The composition of the salts of Great Salt Lake would lead one to expect that the chlorids would prove to be the most common and widely distributed of the saline constituents of the Tooele Valley soils, and such has been found to be the case. In the course of the work a quantitative examination for chlorids was made of 162 samples of soil, and all but 13 samples showed the presence of measurable quantities of chlorids. Of these 13 exceptions 12 were samples from *Artemisia tridentata* (sagebrush) areas which are characterized by a very low total salt content. The sodium-chlorid content of the areas examined, all of which were occupied by vegetation of one type or another, ranged from a trace in the land occupied by Artemisia to over 2 per cent in land occupied by *Allenrolfea occidentalis*. Outside of the sagebrush areas the sodium-chlorid content of most of the samples fell between 0.4 and 1.3 per cent. In a large majority of the samples examined sodium chlorid constituted more than one-half of the total water-soluble material.

Sulphates are usually present in the soils containing an excess of salts. Of 122 samples examined 96 showed the presence of sulphates. It is well recognized through the researches of Hilgard and others that calcium sulphate is a corrective for the soluble "black alkali" (sodium carbonate), the reaction between these salts resulting in the formation of the

[1] F. K. Cameron has shown, however, that while the lake water at its normal concentration does not give an alkaline reaction with phenolphthalein, this reaction will develop simply by diluting the lake water with distilled water. At the normal concentration of the lake, the dissociation of the sodium carbonate is held back through the great number of sodium ions resulting from the dissociation of the sodium chlorid. The lake does, therefore, carry a slight amount of sodium carbonate. (Gardner, F. D., and Stewart, John. A soil survey in Salt Lake Valley, Utah. U. S. Dept. Agr., Div. Soils Field Operations, Rpt. 64, 1899, p. 104–105. 1900.)

relatively insoluble calcium carbonate and neutral sodium sulphate. It is evident that a similar reaction would take place if magnesium sulphate were present, since magnesium also forms an insoluble carbonate. It consequently seemed desirable to examine the carbonate and sulphate measurements with a view to determining to what extent the absence of soluble carbonates was accompanied by the presence of sulphates. Of 122 samples examined for carbonates and sulphates 13 contained neither carbonates nor sulphates, while 13 others contained carbonates but no sulphates, leaving 96 samples containing sulphates. Of these, 78 samples were free from carbonates, 2 samples contained both carbonates and sulphates in measurable quantities, while in the remaining 16 samples traces only of both sulphates and carbonates were present.

VEGETATION OF TOOELE VALLEY

The plant covering of the area under consideration is typical of a large portion of the Great Basin, several of the most important types of vegetation of that region being represented in Tooele Valley. Striking features of this vegetation are (1) the great extent of the areas occupied continuously by a single type of vegetation, (2) the sharpness of the boundaries between the areas occupied by each type, and (3) the great predominance of one or very few species in each type.[1]

CLASSIFICATION OF THE TYPES OF VEGETATION [2]

The principal types of vegetation of Tooele Valley, with the names of the species which are dominant in each, are listed in Table III.

[1] These are common characteristics of the vegetation of arid regions. Thus, Borszczow, as quoted by Ove Paulsen (Studies on the Vegetation of the Transcaspian Lowlands. Copenhagen, 1912, p. 22–23), states:

"Here, as throughout the whole of Aralo-Caspia, it is a few specially characteristic forms which prevail; they repeat themselves continually so that the country has a very monotonous appearance. Other species are only subordinate to these. Where the character of the soil changes, these predominant species sometimes change very quickly and give place to others, which in turn prevail until the soil changes again. This monotony and this repetition of certain species over vast areas is the third characteristic of the vegetation of the Aralo-Caspian countries. It is no doubt a direct consequence of the uniformity of the climate, which again is mainly dependent on the slight vertical relief of the surface. * * *

"In the Aralo-Caspian lands the soil in particular has such a great influence on the vegetation that a change of soil—other conditions remaining the same—often alters the physiognomy totally and almost abruptly without any gradual transitions."

[2] In view of the fact that the ecological plant geography of the Great Basin region is as yet but little understood, it seems inadvisable at this time to attempt to refer the plant associations of this valley to formations. The term "plant association," as used in this paper, signifies an assemblage of plants occupying a relatively uniform environment, having an easily recognizable appearance or "physiognomy" and characterized by the predominance of one or few species.

TABLE III.—*Types of the vegetation in Tooele Valley, Utah, and their dominant species.*

Name of association or other plant community.[1]	Dominant species.
Sagebrush association	Artemisia tridentata.
Sand-hill mixed association	Artemisia tridentata. Juniperus utahensis. Chrysothamnus nauseosus albicaulis.
Kochia association	Kochia vestita.
Shadscale association	Atriplex confertifolia.
Greasewood-shadscale association	Sarcobatus vermiculatus. Atriplex confertifolia.
Grass-flat communities	Distichlis spicata. Sporobolus airoides. Chrysothamnus graveolens glabrata.
Salt-flat communities	Allenrolfea occidentalis. Salicornia utahensis. Salicornia rubra.

[1] Further investigation of the vegetation of the Great Basin region is needed before definite ecological rank can be assigned to the grass-flat and the salt-flat communities.

DISTRIBUTION OF THE TYPES OF VEGETATION

The distribution and relative area in Tooele Valley of the different types of vegetation is shown on the map (Pl. XLII).

Nearly all of the dry land free from alkali salts which retains the original plant covering is occupied by the sagebrush association. (Pl. XLIV.) This type of vegetation covers the southern end of the valley and also extends northward in a narrow fringe along the base of the Stansbury Range to within about 5 miles of Great Salt Lake. Few vestiges of the original cover remain on the eastern side of the valley, but there can be little doubt that sagebrush formerly occupied the bench lands and alluvial fans at the foot of the Oquirrh Range. The dominant species of this association is also found along gullies and in depressions, in the midst of areas otherwise occupied by the Kochia and shadscale associations. It is probable that most of the land now occupied by the sagebrush association was laid bare before the waters of Lake Bonneville had become strongly saline.

South of the center of the valley a rather extensive area of sand hills is covered by what may be designated the sand-hill mixed association. In this association also sagebrush is the dominant plant, but there is a plentiful admixture of Utah juniper and certain species of rabbit brush (Chrysothamnus), together with many herbaceous plants more or less peculiar to sandy soils. Botanically, this is the most varied and interesting type of vegetation occurring in Tooele Valley.

The middle portion of the valley resembles the upper portion in the dryness of the soil and subsoil during the summer, but differs in the high salt content of the subsoil. This territory is divided between two types of vegetation, the Kochia (Pl. XLVI) and the shadscale (Pl. XLVII, fig. 1) associations. The former occupies a sharply defined interrupted belt extending well across the valley just south of the sagebrush area and also penetrates the latter in the form of tongues and islands, which occur here and there far toward the head of the valley. (Pl. XLIII, fig. 2.) Lying just below the main Kochia belt an extensive tract is occupied by the shadscale association, which on the western side of the valley is prolonged in a gradually narrowing strip to the north end of the Stansbury Range. While the boundary between the sagebrush and Kochia associations is often very sharp (Pl. XLVI, fig. 1), that between the Kochia and shadscale associations is much less distinct. It is probable that the water of Lake Bonneville had become strongly saline before the areas now occupied by the Kochia and shadscale associations were laid bare and that the subsequent precipitation has been too small to leach the salts then deposited to a greater depth than 1 or 2 feet.

As the elevation of the land diminishes, the pure shadscale is gradually replaced by an association of greasewood and shadscale. The frontier between the two associations is not sharply defined (Pl. XLVII, fig. 2), scattered greasewood plants appearing first along gullies or draws and gradually, as Great Salt Lake is approached, mingling everywhere with the shadscale. This association extends to the edge of the lake, covering the summits of the low ridges and hummocks which are interspersed among the salt flats. In Tooele Valley greasewood scarcely occurs in a pure association, but is practically everywhere mingled with shadscale.

Between the main greasewood-shadscale area and the salt flats occur the grass flats, a nearly level expanse, marshy in places, covered largely with grasses and with a species of Chrysothamnus. (Pl. XLVIII, fig. 3.)

Near the present margin of the lake basinlike areas are found, many of which are doubtless under water at times. (Pl. XLIII, fig. 1; Pl. XLVIII, fig. 1.) The larger of these appear in summer as bare expanses covered with a glistening crust of white salts. Near their margins, however, and often covering the entire surface of the smaller depressions certain very salt-resistant plants occur, either scattered over the otherwise bare ground or forming rather dense colonies. The most important of these plants are *Allenrolfea occidentalis* (Pl. XLVIII, fig. 1), which is most at home on the slightly higher margins of the basins, and two species of glasswort (Salicornia)—one perennial (*S. utahensis*) (Pl. XLVIII, fig. 2), the other annual (*S. rubra*).

To recapitulate, the dry, well-drained, nonsaline land in the upper part of the valley is occupied chiefly by the sagebrush association; the dry saline land near the center is covered with a vegetation of Kochia or of shadscale; the land in the lower part of the valley, which is often dry on the surface but has a moist subsoil, bears a mixed vegetation of greasewood and shadscale; while the lowest areas near the lake shore, where the soil is strongly saline to the surface and where during much of the year even the first foot is wet, bear the salt-flat type of vegetation. The grass flats occupy a moist, moderately saline area lying between the two preceding. These relationships are shown in Table XVIII, p. 413, and are graphically represented in figure 13 on p. 412.

In the following pages descriptions are given of the several associations and other plant communities, arranged in the order shown in Table III.

SAGEBRUSH ASSOCIATION

Topographical Relations

The sagebrush association is one of the most important types of vegetation of the Great Basin region. In Tooele Valley (see map, Pl. XLII) it occurs chiefly on the bench lands which skirt the mountains. The best growth of sagebrush (apart from that on the sand hills as described later) is found on the alluvial fans which are situated near the mouths of canyons. In such places the moisture received directly as precipitation is probably supplemented by water from the hills. This type of vegetation extends across the southern end of the valley and probably at one time formed a continuous belt, although fire and cultivation have greatly diminished the area originally occupied, especially on the east side. Farther down the valley, below the main area occupied by this association, sagebrush is found only on sand hills, along drainage channels, and in depressions—places where the moisture conditions are more favorable and more of the alkali has been leached out than in the surrounding areas.

Botanical Composition

This association in its typical form is dominated by *Artemisia tridentata* (Pl. XLIV) as almost the sole woody plant. In less typical phases two or three species of rabbit brush (Chrysothamnus) occur.[1] Many species of perennial herbs associate with the sagebrush, especially in those portions of the area which lie nearest the foothills. The following list includes all shrubs and perennial herbs which were noted as belonging to the sagebrush association.

[1] These are never abundant and never attain their maximum size where they occur in the typical sagebrush association in Tooele Valley. They appear more at home where associated with Artemisia on the sand hills, and at roadsides and along ditches in areas which were formerly covered with the sagebrush association.

PERENNIAL SPECIES OF THE SAGEBRUSH ASSOCIATION [1]

Common or frequent

Agropyron spicatum (Pursh) Rydb.
Eriocoma cuspidata Nutt.
Poa sandbergii Vasey
Sitanion jubatum J. G. Smith
Zygadenus paniculatus Wats.
Eriogonum ovalifolium Nutt.
Opuntia sp.
Malvastrum coccineum (Pursh) Gray
Phlox longifolia Nutt.
Castilleja linariaefolia Benth.
Artemisia tridentata Nutt.
Chrysothamnus marianus Rydb.
Chrysothamnus nauseosus albicaulis (Nutt.) Rydb.
Chrysothamnus pumilus Nutt.
Erigeron pumilus Nutt.
Gutierrezia sarothrae (Pursh) B. and R.
Senecio uintahensis A. Nels.

Less frequent or rare

Stipa comata Trin. and Rupr.
Atriplex canescens (Pursh) James
Delphinium burkei Greene
Cowania stansburiana Torr.
Astragalus arietinus Jones
Astragalus beckwithii T. and G.
Astragalus utahensis T. and G.
Anogra pallida (Lindl.) Brit.
Gaura parviflora Dougl.
Pachylophus marginatus (Nutt.) Rydb.
Lappula caerulescens Rydb.
Lappula occidentalis (Wats.) Greene
Thalesia fasciculata (Nutt.) Brit.
Antennaria dimorpha (Nutt.) T. and G.
Balsamorrhiza hirsuta Nutt.
Balsamorrhiza sagittata (Pursh) Nutt.
Chaenactis douglasii H. and A.
Chrysopsis villosa (Pursh) Nutt.
Crepis occidentalis Nutt.
Layia glandulosa H. and A.
Leucelene ericoides (Torr.) Greene
Ptilocalais nutans (Geyer) Greene
Tetradymia inermis Nutt.

Numerous annual and biennial plants occur in this association. By far the most abundant of these are two introduced species, *Bromus tectorum* and alfilaria (*Erodium cicutarium*), which in many places cover the ground among the "sage" bushes with a dense mat of vegetation. The more abundant or otherwise conspicuous annual and biennial plants of the sagebrush association are given in the following list:

ANNUAL AND BIENNIAL SPECIES OF THE SAGEBRUSH ASSOCIATION

Bromus tectorum L.
Festuca octoflora hirtella Piper
Arabis longirostris Wats.
Draba sp.
Sophia filipes (Gray) Heller
Sophia pinnata (Walt.) Brit.
Erodium cicutarium L'Her.
Mentzelia dispersa (Wats.) A. Nels.
Mentzelia laevicaulis (Dougl.) T. and G.
Anogra albicaulis (Pursh) Brit.
Phacelia linearis (Pursh) Holz.
Cryptanthe sp.
Lappula cupulata (Gray) Rydb.
Lappula subdecumbens (Parry) Nels.
Amsinckia tessellata Gray

APPEARANCE

The characteristic appearance of the sagebrush association is illustrated in Plate XLIV, figure 1. During the early summer, when their maximum growth is taking place, the sagebrush plants present a silvery

[1] In this and all following lists of species the families are arranged in the sequence of Engler and Prantl (Die Natürlichen Pflanzenfamilien), while the genera are arranged alphabetically under each family.

appearance, due to the hairy covering of the young leaves. From the middle of summer to the following spring the plants having lost many of their leaves and the dark stems being more in evidence, the appearance of the vegetation is decidedly different. Still another aspect is that of the early fall when the Artemisia plants are in flower and give a yellowish color to the vegetation. The contrast between the comparatively vivid and varied appearance of the vegetation in early summer and its monotonous aspect during the rest of the year is heightened by the fact that nearly all of the flowering herbs belonging to this association die, at least to the ground, long before the close of the summer.

In some parts of the valley, especially where the soil is sandy, the plants of sagebrush are tall, vigorous, and stand close together. In other and more extensive areas, where the moisture conditions are less favorable, they are scattered and stunted, and the proportion of new growth to old wood is small.[1] The plants, in fact, look as if they were slowly dying in such areas. By far the best growth of *Artemisia tridentata* is found on the sand hills and along irrigating ditches. In the greater part of the area occupied by this association the plants are from 2½ to 4 feet high. Their frequency is indicated in figure 3, which represents a quadrat[2] platted early in the month of August in a typical portion of this association as it occurs in Tooele Valley.

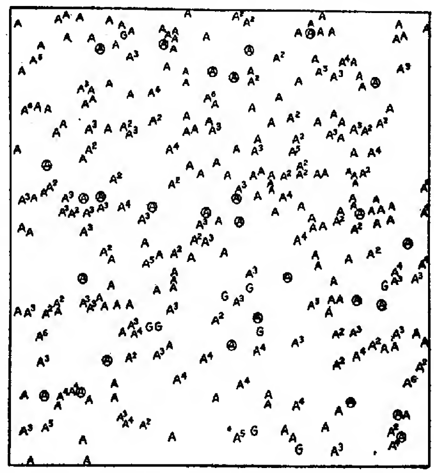


FIG. 3.—A representative 10-meter quadrat of the sagebrush association, showing the location of each individual of *Artemisia tridentata* (*A*) and of *Gutierrezia sarothrae* (*G*), these being the only woody species present. The figures show the number of main branches of the Artemisia plants and hence indicate their relative size. The absence of a figure indicates that there was only one large stem. A circle around the *A* indicates a dead plant of Artemisia. *Bromus tectorum* was very abundant around the Artemisia bushes, and Sitanion was also present. These two grasses are not shown on the quadrat.

The associated herbs, although of many species, are not sufficiently numerous individually nor sufficiently large in size to materially affect the aspect of the vegetation, even when they are at the height of their

[1] These slow-growing plants reach a considerable age without attaining a large stem diameter. Twenty-three annual rings were counted in a stem barely 2½ inches in cross section.

[2] For descriptions of the method of quadrats, see Clements, F. E., Research Methods in Ecology, Lincoln, 1905, p. 161–176; and also his Plant Physiology and Ecology, New York, 1907, p. 202–210.

growth and blossoming. Moreover, they are apt to be partly hidden, owing to their habit of growing close among the stems of the sagebrush. After midsummer most of the herbaceous species die, at least to the ground, and during the rest of the year typical areas when viewed from a little distance appear to contain no species other than *Artemisia tridentata*.

PHYSICAL CONDITIONS INDICATED

The soils occupied by the sagebrush association, which consist largely of products of erosion deposited upon the bed of the ancient Lake Bonneville, are rather coarse in texture and often contain much gravel. All available data concerning the moisture conditions and salt content of the soil in typical portions of this association as it occurs in Tooele Valley are given in Table IV.

TABLE IV.—*Sagebrush association: Moisture conditions and salt content of the soil in typical areas.*[1]

Item.	Depth of soil (feet.)	Date of collection.												
		June.									August.			Average.
		3	5	5	15	15	15	15	17	17	3	7	7	
No. of sample	....	15	25	27	36	37	38	39	40	41	104	111	115	
Moisture equivalent	1	......	......	13.1	15.9	16.7	12.6	15.7	18.4	......	......	12.1	9.3	14.2
	2	......	......	15.6	17.4	17.7	22.9	14.7	19.1	......	......	8.9	9.0	15.6
	3	......	......	23.8	13.3	22.2	24.5	......	15.2	......	......	7.5	9.0	16.5
	4	......	......	19.6	11.6	......	23.4	......	......	......	......	......	8.7	15.8
Wilting coefficient	1	......	......	7.1	8.6	9.1	6.8	8.5	10.0	......	......	6.6	5.0	7.7
	2	......	......	8.5	9.4	9.6	12.4	8.0	10.4	......	......	4.8	4.9	8.5
	3	......	......	12.9	7.2	12.0	13.3	......	8.2	......	......	4.1	4.9	8.9
	4	......	......	10.6	6.3	......	12.7	......	......	......	......	......	4.7	8.6
Moisture content above or below the wilting coefficient	1	......	......	− .7	−1.4	−3.0	−1.2	−3.7	−5.0	......	......	......	......	−2.5
	2	......	......	+3.1	+ .4	−1.5	+ .3	−2.5	−4.1	......	......	......	......	− .6
	3	......	......	−4.4	+ .7	−4.4	+3.7	......	−3.2	......	......	......	......	−1.3
	4	......	......	−1.0	0	......	+4.0	......	......	......	......	......	......	+1.0
Salt content	1	0.03	0.04	.03	.04	.03	.03	.03	.03	0.03	0.03	.03	.03	.03
	2	.03	......	.03	.04	.06	.03	.03	.03	.03	.03	.02	.03	.03
	3	......	......	.08	.03	.12	.05	......	.02	......	......	.02	.03	.05
	4	......	......	.10	.03	......	.12	......	......	......	......	......	.05	.07
	5	......	......	.05	......	......	.10	......	......	......	......	......	......	.07

[1] All data in this table are stated in percentages of the dry weight of the soil. The moisture contents with a plus sign (+) represent moisture available for growth (above the wilting coefficient), while those with a minus sign (−) represent a corresponding deficit of available moisture (below the wilting coefficient).

SOIL MOISTURE.—Typical sagebrush land is characterized by a rather light texture of the soil, as is indicated by the relatively low moisture equivalent. In such soil water penetrates readily to considerable depths, and the run-off must be small. Consequently, although the moisture-holding capacity is low, the total quantity of water available to deep-rooted plants is considerable.

The rapid growth of the sagebrush plants in the early part of the summer results in a speedy exhaustion of the moisture available for growth, and in most years the water content of the soil to the depth reached by the roots is probably reduced by midsummer to below the

wilting coefficient in much the greater part of the area occupied by this association. That this is the case is strongly indicated by the fact that most samples of soil collected during the month of June, 1912, showed very little or no moisture above the wilting coefficient to a depth of 4 feet (Table IV).

In places where the conditions for the reception of water and removal of alkali salts are more than usually favorable—e. g., along drainage channels, in depressions, and in places where the soil has been loosened by burrowing animals—there is probably available moisture within reach of the roots during a longer period. *Artemisia tridentata* was not seen growing under natural conditions where the water table is near the surface of the soil.

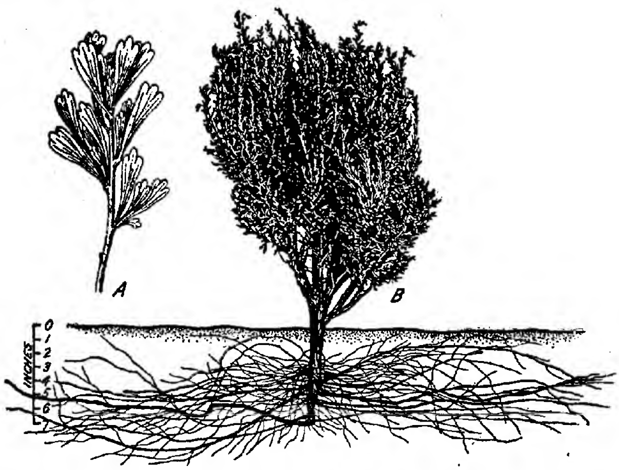


FIG. 4.—*Artemisia tridentata* (sagebrush): *A*, Detail showing the wedge-shaped, 3-toothed leaves by which this plant is easily recognized; *B*, a small plant growing where hardpan occurred, showing the deflection of the taproot from a vertical to a horizontal direction after reaching a depth of 5 inches.

Optimum soil-moisture conditions for the growth of *Artemisia tridentata* are rarely realized in Tooele Valley. This is shown by the much larger size and more vigorous appearance of the plants which grow on sand hills and along irrigating ditches. In many places the maximum depth reached by the roots is only from 18 to 30 inches and is marked by the presence of a hardpan consisting of coarse gravel cemented by calcareous material. The depth at which this hardpan is formed probably represents the limit of penetration of the rain water, and consequently most of the roots of the sagebrush do not penetrate farther. The shallowness of the moisture-holding layer of the soil greatly reduces the absolute quantity of moisture available for growth. The effect is shown in the thin stand and in the small size and sickly appearance of the plants (fig. 4). The eastern part of the valley, where most of the dry-

farming area is situated, was in all probability once covered with sagebrush vegetation, although few traces of it now remain. Here the conditions were probably more favorable for the growth of this plant than in most of the area still occupied by it.

SALINITY.—Reference to Table IV shows that in the typical sagebrush land of Tooele Valley the salt content of the soil is extremely low—lower, in fact, than in many soils of humid regions. Near the lines of contact with other associations, however, *Artemisia tridentata* frequently grows where much salt is present at a depth of 30 or 40 inches. In such places the saline subsoil is an effectual barrier to the penetration of the roots, the depth of soil from which the plant must extract its entire supply of water is correspondingly limited, and as a result the plants are scattered, very small, and give every appearance of suffering from drought.

An excellent example of this condition was observed on the west side of the valley, where in a spot of considerable size the plants of Artemisia were widely spaced, rarely more than 2 feet high, and had many dead branches. Samples of soil collected in this spot on June 3 gave salt contents and moisture contents as follows:

TABLE V.—*Salt content and moisture content (above or below the wilting coefficient) at different depths of the soil where the sagebrush was small and suffering.*

Depth.	Salt content.	Moisture content above or below wilting coefficient.
Feet.	*Per cent.*	*Per cent.*
1	0.05	−2.0
2	.18	−2.2
3	.53	−3.4
4	.64	+.8
5	.59	

The roots of the plant alongside this boring penetrated to a depth of only about 2 feet, at which point the taproot had died, and development was continued by horizontal laterals. The feeding roots were mostly confined to the first foot of the soil.

The most extreme condition as regards salinity which was noted at any point in Tooele Valley where *Artemisia tridentata* grew was in a small pocketlike depression among the sand hills where salts had accumulated as a result of seepage from the surrounding dunes and where very small sickly plants of sagebrush grew in company with greasewood (Sarcobatus) and Kochia. The salt contents were as follows: First foot, 0.16 per cent; second foot, 0.51 per cent; third foot, 0.67 per cent; fourth foot, 0.66 per cent. The presence here of living plants of sagebrush is doubtless explained by the fact that large seed-producing plants of this species were growing on the surrounding dunes and that the salt content of the

surface soil was not high enough to prevent the germination and seedling growth of the Artemisia.

SUMMARY OF PHYSICAL CONDITIONS.—The observations made in Tooele Valley lead to the conclusion that in this area a good stand and growth of sagebrush indicates (1) a rather coarse textured, readily permeable soil, with low run-off and good underdrainage (water table low); (2) a depth of soil of at least 3 feet, in which water can be stored and into which the roots of plants may easily penetrate; (3) at least 3 feet of soil free from alkali salts in quantity sufficient to injure ordinary crop plants.

ADAPTATIONS TO THE PHYSICAL CONDITIONS

The herbaceous species of the sagebrush association are for the most part shallow rooted, and, hence, are dependent upon the moisture of the upper soil. The great majority of them grow so rapidly during the spring and early summer that they are able to complete their development and ripen seed before the water content of the first foot or two of the soil has been exhausted to the wilting coefficient. When this occurs, they die, at least to the ground.[1] After the middle of July few living plants except sagebrush are visible in typical areas of this association.

The dominant species, *Artemisia tridentata* (sagebrush) is able to continue growth during a longer period. As shown in figure 5 and in Plate XLIV, figure 2, it possesses a "generalized" type of roots[2]—i. e., a highly developed system of laterals in the upper soil and also a deeply penetrating taproot. The former are admirably adapted for securing the moisture which penetrates only to a small depth during light rains and for which in spring and early summer this plant must compete with the numerous associated annual and perennial herbs. By means of its taproot the plant can also avail itself of moisture stored at greater depths[3] in the readily permeable soils which are preferred by this association.

The great development of superficial lateral roots favors rapid growth so long as abundant moisture is present in the upper soil, while the deep penetration of the taproot permits the plant to continue growth at a slower rate long after most of the herbaceous species of this association have withered away. In typical areas of sagebrush vegetation as represented in Tooele Valley (Pl. XLIV, fig. 1) the available moisture is probably exhausted before the end of the summer in all depths of soil

[1] They are for the most part "drought escaping" rather than "drought enduring." See Kearney, T. H., and Shantz, H. L., The water economy of dry-land crops, U. S. Dept. Agr., Yearbook, 1911, p. 354-357. 1912.

[2] See Cannon, W. A., The Root Habits of Desert Plants, Washington, p. 87, 1911. (Carnegie Inst., Washington, Pub. 131.)

[3] Plate XLIV, figure 2, reproduced from a photograph taken in the vicinity of Nephi, Utah, shows the taproot of *Artemisia tridentata* extending vertically to a depth of over 15 feet. The root penetration of this plant under optimum conditions was not studied in Tooele Valley, but it is unlikely that in most of the area there occupied by this association the roots reach so great a depth. In this locality the deepest rooting plants are doubtless those which grow on the sand hills.

reached by the Artemisia roots. The plants then lose many of their leaves and make no further growth until the following spring.[1]

The total transpiring surface is small in proportion to the size of the plant, especially where the physical conditions are least favorable, and this helps to prevent rapid exhaustion of the available soil moisture. The limited amount of new growth made during exceptionally dry seasons diminishes the danger of death from drought. Another circumstance which serves as a protection from this danger is the thinness of the stand. Even on the sand hills, where the conditions are most favorable for their growth, the sagebrush plants are rarely crowded. In proportion as the soil-moisture conditions depart more and more from the optimum for this species, the plants are farther and farther apart. Each individual (Pl. XLIV, fig. 1) is surrounded by a space of ground which is bare during the greater part of the year, although producing a few shallow-rooted herbaceous plants in spring and early summer. The wide spacing of the plants is indicated in figure 3.

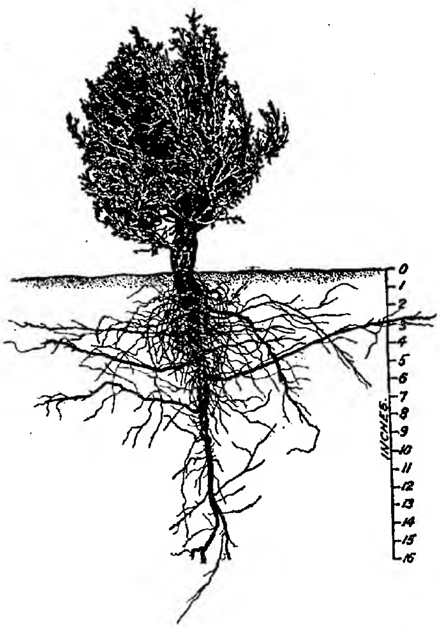


FIG. 5.—A small plant of sagebrush (*Artemisia tridentata*), showing the deeply penetrating taproot and good development of superficial lateral roots typical of this species.

EFFECTS OF DISTURBING FACTORS: SUCCESSIONS

During the summer and autumn large areas of sagebrush are often burned over. The fire consumes the dry herbaceous growth and the sagebrush plants are usually burned to the ground. They do not sprout up from the old stumps, and the result is usually the complete removal of the Artemisia. In the following year a mat of herbaceous vegetation, composed chiefly of *Bromus tectorum* and *Erodium cicutarium*, covers the

[1] Sagebrush is therefore to be classed as a "drought-enduring" species. See Kearney and Shantz, op. cit., p. 354, 355.

ground among the blackened stumps. After a few years Gutierrezia is likely to become the dominant plant on these burned-over areas. (Pl. XLV, fig. 1.) This, in turn, is followed by the sagebrush, which gradually reestablishes itself.

In sagebrush land which has been plowed up and subsequently abandoned, the removal of the shrubs favors the development of various annual and biennial weeds, such as *Bromus tectorum*, alfilaria (*Erodium cicutarium*), pigweeds (species of Amaranthus), Sunflower (*Helianthus annuus*), wild tomato (*Splanum triflorum*), vervain (*Verbena bracteosa*), etc. As time goes on, *Gutierrezia sarothrae*, a small, much-branched, yellow-flowered composite, often becomes established and maintains itself for a period which is short or long accordingly as the conditions are more or less favorable for the reestablishment of the sagebrush. Sooner or later the Artemisia reappears (Pl. XLV, fig. 2), and unless fire or some other disturbing factor intervenes, the territory is eventually reconquered by the original association. (Pl. XLV, fig. 3.)

The succession after either fire or breaking may be shortened, Artemisia following immediately after the annual weed stage, without the intervention of Gutierrezia. As a rule, however, the succession comprises (1) a growth of annual and biennial weeds, (2) a growth of the perennial Gutierrezia, and (3) the return of the original sagebrush vegetation.

Grazing does not materially alter the sagebrush vegetation, although diminishing the numbers of many of the herbaceous species. *Artemisia tridentata* itself is rarely eaten and is, in fact, benefited by grazing, since the plants which compete with it for the soil moisture are thereby removed.

Variations from the Typical Association

Sagebrush with Kochia and with Shadscale.—Near the lower limit of the main area occupied by sagebrush this association comes into contact with the Kochia and shadscale associations, and the dominant species of the three associations often grow together in a mixed community. The plants of Artemisia which push out farthest into areas occupied by these other associations are confined to drainage channels, depressions, and the vicinity of animal burrows. In such places the conditions as to soil moisture are more favorable and the greater penetration of the rain water has leached the salts into lower depths of soil than is generally the case in Kochia and shadscale land. But along the frontiers of these associations scattered, small, and sickly looking plants of Artemisia mingle directly with Kochia or with shadscale.

Borings made where *Artemisia tridentata* and *Atriplex confertifolia* grow side by side invariably showed the presence of salts in the second, or, at the deepest, in the third foot of the soil. (Table VI.) The sagebrush roots are unable to penetrate this saline subsoil, and the total quantity of water available for the growth of this plant is correspondingly limited.

TABLE VI.—*Salt content of the soil at points where Artemisia tridentata and Atriplex confertifolia grew side by side.*

Depth of soil.	Salt content in boring No.—			
	59	60	95	96
Feet.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0.06	0.08	0.12	0.04
2	.27	.53	.53	.04
3	....	....	1.02	.76
4	....	....	1.36	....

SAGEBRUSH WITH JUNIPER.—The Utah juniper (*Juniperus utahensis*) is abundant on the lower slopes of the mountains and also pushes down into the upper part of Tooele Valley, where it occurs scatteringly in the midst of areas occupied by the typical sagebrush association (see background of Pl. XLIV, fig. 1), as well as on the sand hills. The presence of juniper away from the sand hills usually indicates a stonier soil than that on which the typical sagebrush association occurs.

SAND-HILL MIXED ASSOCIATION

TOPOGRAPHICAL RELATIONS

The sand-hill mixed association covers a limited area towards the south end of the valley, lying directly in the path of the winds from the southwest which sweep over the low divide separating Tooele Valley from Rush Valley. Even when the air is nearly motionless in other parts of the valley, a sandstorm may often be seen blowing in this quarter. The sand is mostly heaped in dunes, which form more or less continuous ridges having a general north and south trend. In places where "blow-outs" have taken place the ground is sometimes bare, but for the most part it is fairly well covered with vegetation.

APPEARANCE AND BOTANICAL COMPOSITION

As is usually the case in arid regions, the vegetation of the sand hills is characterized by the presence of a large number of species—far more than occur in any other plant association of Tooele Valley. The appearance of the vegetation as viewed a short distance away is determined by the presence of a few woody species, notably sagebrush (*Artemisia tridentata*) and juniper (*Juniperus utahensis*). Sagebrush is much the most abundant of the woody plants of the sand hills, and the individual plants of this species which grow there are the largest and thriftiest found anywhere in Tooele Valley under natural conditions.

The Utah juniper is fairly abundant on the sand hills. It occurs as a large shrub or small tree, rarely exceeding 10 feet in height. Two species of rabbit brush (*Chrysothamnus nauseosus albicaulis* and *C. pumilus*) are also common, while the remaining woody species of this

association, *Atriplex canescens*, *Grayia spinosa*, *Sarcobatus vermiculatus*, and *Purshia tridentata*, are relatively infrequent. The predominance of woody plants distinguishes the sand-hill association of Tooele Valley from the corresponding type of vegetation in the Great Plains east of the Rocky Mountains.[1]

Next to the shrubs, perennial herbs are the most important members of this association. Noteworthy among these are two characteristic sand-loving species, *Psoralea lanceolata* and *Abronia salsa*. Certain bunch grasses, *Eriocoma cuspidata*, *Stipa comata*, and *Agropyron spicatum*, are also important constituents of this vegetation. A few annual and biennial species are to be seen during the first weeks of summer, but the plants are too small and too short lived to greatly influence the appearance of the vegetation.

The following list includes the more important species noted as occurring in the sand-hill mixed association:

PERENNIAL SPECIES

Juniperus utahensis (Englm.) Lemm.
Agropyron spicatum (Pursh) Rydb.
Eriocoma cuspidata Nutt.
Stipa comata Trin. and Rupr.
Eriogonum ovalifolium Nutt.
Eriogonum kearneyi Tidestrom
Atriplex canescens (Pursh) James
Eurotia lanata (Pursh) Moq.
Grayia spinosa (Hook.) Moq.
Sarcobatus vermiculatus (Hook.) Torr.
Abronia salsa Rydb.
Purshia tridentata (Pursh) DC.
Psoralea lanceolata Pursh
Gilia pungens (Torr.) Benth.
Lappula occidentalis (Wats.) Greene
Castilleja linariaefolia Benth.
Artemisia tridentata Nutt.
Chrysothamnus nauseosus albicaulis (Nutt.) Rydb.
Chrysothamnus pumilus Nutt.
Layia glandulosa H. and H.
Senecio uintahensis A. Nels.

ANNUAL AND BIENNIAL SPECIES

Abronia cycloptera Gray
Eriogonum cernuum Nutt.
Lepidium pubecarpum A. Nels.
Erodium cicutarium L'Her.
Gilia leptomeria Gray
Crytanthe sp.
Lappula sp.

PHYSICAL CONDITIONS INDICATED

The soil is nearly pure sand and is easily moved by the wind. The conditions for penetration of the total rainfall are excellent and the run-off is negligible. The great depth of loose soil is favorable to storage of water during a long period after rains. Only one soil boring in this association was made (June 3), but the location was apparently in all respects a typical one and the resulting data (Table VII) probably represent the average conditions of moisture and salt content of the soil where this type of vegetation occurs.

[1] Shantz, H. L., Natural vegetation as an indicator of the capabilities of land for crop production in the Great Plains area. U. S. Dept. Agr., Bur. Plant Indus. Bul. 201, p. 58–60. 1911.

TABLE VII.—*Sand-hill mixed association: Moisture conditions and salt content of the soil in a typical area.*[1]

Depth (feet).	Moisture equivalent.	Wilting coefficient.	Moisture content above or below the wilting coefficient.	Salt content.
1	9.2	5.0	−0.1	0.03
2	9.7	5.3	+0.7	.03
3	6.2	3.4	+1.1	.03
4	5.8	3.1	+1.3	.04
5	....	....	....	.01
6	....	....	....	.01

[1] All data are in percentages of the dry weight of the soil.

If the data given in Table VII may be taken as representative, land occupied by this association is characterized by the following soil conditions: (1) A low moisture-holding capacity, as indicated by the low moisture equivalents, (2) available moisture present, at least during the fore part of the summer, at a depth attainable by the more deeply penetrating roots, and (3) a very low salt content.

ADAPTATIONS TO THE PHYSICAL CONDITIONS

The soil-moisture conditions of the sand hills are obviously such as to favor plants with deeply penetrating roots, and, accordingly, large woody plants are predominant in this association. Sagebrush, the most abundant woody species, is noteworthy for the great depth reached by its taproot when the conditions are favorable. Of the herbaceous species of this association, some have a well-developed taproot, while others produce an abundance of superficial roots. The shallow-rooted herbs, being dependent upon the moisture of the surface soil, mostly complete their growth and ripen seed early in the summer. Certain of the perennial herbs, notably *Psoralea lanceolata*, spread by slender, creeping rootstocks and can therefore withstand frequent burial. This plant is excellently adapted to colonizing the blow-outs and may be regarded as the pioneer plant of the moving sands.

KOCHIA ASSOCIATION[1]

TOPOGRAPHICAL RELATIONS

The Kochia association (Pl. XLVI) occupies a narrow and nearly contiguous belt which extends across the valley along the lower boundary of the sagebrush area and lies between the latter and the shadscale area. (See map, Pl. XLII.) This type of vegetation likewise occurs as islands of greater or less extent scattered through the sagebrush zone, well

[1] While this plant association is one of the most important in Tooele Valley, it appears to be a much less prominent feature of the vegetation in other portions of central and western Utah.

toward the head of the valley. (Pl. XLIII, fig. 2.) The boundaries between the areas occupied by the Kochia and by the sagebrush associations are usually very sharply defined. Equally abrupt is the change in salt content of the soil, as is well exemplified by the results of borings which were made on either side of the line of contact shown in Plate XLVI, figure 1. The location of the boring in the sagebrush association is marked by the position of the soil tube shown in the illustration. The two borings were only 20 feet apart. The results are given in Table VIII.

TABLE VIII.—*Salt content (in percentages of the dry weight of the soil) on either side of a line of contact between the sagebrush and Kochia associations.*

Depth (feet).	Sagebrush.	Kochia.
1	0.03	0.31
2	.03	1.49

On the other hand, the boundaries between the Kochia and shadscale associations are usually indefinite.

Kochia vestita, sometimes locally known as "white sage," which is the dominant species of the Kochia association, is also a frequent component of the shadscale and greasewood-shadscale associations, reaching the shore of Great Salt Lake with the latter association. But the small size of the plants as compared with those of shadscale and of greasewood makes Kochia an inconspicuous member of these associations.

In typical portions of this association *Kochia vestita* is almost the only species of flowering plant, except that where grazing animals are kept off the land, a small grass, *Poa sandbergii*, is very abundant. Few other species occur, and these are seldom represented by numerous individuals. The following list includes all species of flowering plants which were noted as occurring in typical areas of the Kochia association:

BOTANICAL COMPOSITION

Kochia vestita (Wats.) A. Nels.
Poa sandbergii Vasey
Erodium cicutarium L'Her.
Lepidium sp.
Sphaerostigma pubens (Wats.) Rydb.
Opuntia sp.
Gutierrezia sarothrae (Pursh) B. and R.

APPEARANCE

The Kochia association is the most uniform in appearance of the types of vegetation occurring in this valley (Pl. XLVI, fig. 2). It is virtually a 1-species association. The height of the plants varies but slightly over large areas and usually does not exceed 6 inches. Owing to the low growth and the hairiness of the plants (see text fig. 7 and Pl. XLVI, fig. 3), an area of Kochia presents at a little distance the homogeneous appearance of a gray blanket. Even at a distance of several miles, the strips

and islands occupied by this plant are easily distinguishable from surrounding areas of sagebrush vegetation (Pl. XLIII, fig. 2). The contrast is especially striking in spring and early summer when the sagebrush has a silvery green color, which is quite distinct from the dull gray of the Kochia.

When viewed closely (Pl. XLVI), the plants are found to be separated by patches of bare ground which vary in size as the physical conditions are more or less favorable. In a more distant view the light ashy color of the soil occupied by this association blends with the color of the plants themselves, and this tends to create the impression that the plant covering is dense. In fenced areas occupied by this association the color is modified to a yellowish or brownish gray during a few weeks in the early part of the summer, owing to the abundant fruiting heads of a small grass, *Poa sandbergii* (Pl. XLVI, fig. 3). But most of this land is grazed by sheep, which soon extirpate the grass or at least prevent its flowering, while leaving the Kochia practically undisturbed. The distribution of the plants of Kochia and of Poa in a typical, unmodified quadrat of this association is shown in figure 6.

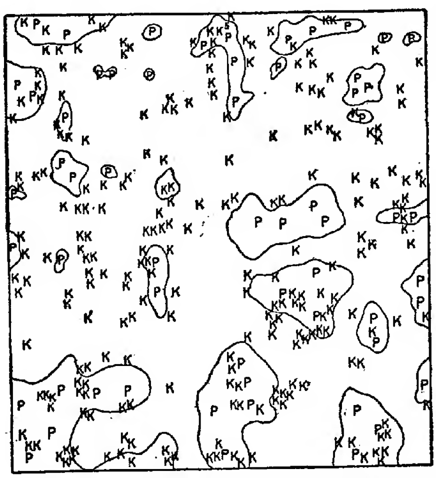


Fig. 6.—A representative 10-meter quadrat of the Kochia association, showing the location of each tuft of Kochia (*K*) and of each matlike colony of *Poa sandbergii* (*P*).

Physical Conditions Indicated

The type of land occupied by the Kochia association in its typical form is uniform and well defined. The soil is remarkably homogeneous to a depth of several feet, fine in texture, and close in structure. Unlike sagebrush and shadscale lands, there is usually little gravel present. The smooth, polished condition of the surface after it has been wet indicates that this soil puddles readily. The conditions for the penetration of water are, therefore, unfavorable, and the run-off is doubtless high.

TABLE IX.—*Kochia association: Moisture conditions and salt content of the soil in typical areas.*[1]

Items.	Depth of soil (feet).	Date of collection.										
		June.					July.			August.		Average.
		1	1	7	18	18	3	5	12	3	7	
No. of sample	......	4	5	32	44	45	65	70	78	105	116	
Moisture equivalent	1	23.0	35.8	......	21.7	......	26.0	24.7	......	......	23.9	25.8
	2	25.5	25.2	......	30.3	......	26.4	29.4	......	......	25.3	27.0
	3	33.3	35.0	......	29.4	......	34.5	36.8	......	......	32.4	33.5
	4	31.4	34.2	......	24.4	......	35.0	34.3	......	......	32.5	31.9
Wilting coefficient	1	12.5	19.5	......	11.8	......	14.1	13.4	......	......	13.0	14.0
	2	13.9	13.7	......	16.5	......	14.3	16.0	......	......	13.7	14.7
	3	18.1	19.0	......	16.0	......	18.7	20.0	......	......	17.6	18.2
	4	17.0	18.6	......	13.2	......	19.0	18.6	......	......	17.7	17.3
Moisture content above or below wilting coefficient	1	−1.8	−9.2	......	−4.2	......	−6.2	−5.8	......	......	......	−5.4
	2	−1.5	−2.6	......	−.3	......	+1.6	−6.1	......	......	......	−1.8
	3	−5.4	−5.3	......	−2.0	......	−2.0	+2.0	......	......	......	−2.5
	4	−3.2	−5.0	......	−1.9	......	+1.6	−3.3	......	......	......	−2.4
Salt content	1	.05	.08	.04	.22	.14	.07	.06	.18	.31	.05	.12
	2	.30	.16	.14	1.20	.30	.47	.32	.80	1.49	.31	.55
	3	.82	.60	.52	1.14	1.56	1.10	.88	1.36	1.36	.92	1.02
	4	......	.70	.78	1.02	......	1.43	.97	......	1.76	1.10	1.11

[1] All data in this table are stated in percentages of the dry weight of the soil. The moisture contents with a plus sign (+) represent moisture available for growth (above the wilting coefficient), while those with a minus sign (−) represent a corresponding deficit of available moisture (below the wilting coefficient).

SOIL MOISTURE.—The moisture equivalents given in Table IX indicate that the moisture-holding capacity of the soil is much higher in Kochia land than in sagebrush land. The moisture contents in typical areas show that as early as the first of June, 1912, the soil to a depth of 4 feet was usually devoid of water available for plant growth. The deficit was usually greatest in the surface foot, partly no doubt because of surface evaporation and partly because of the shallow-rooting habit of *Kochia vestita*.

SALINITY.—The soil in typical Kochia land, at least in Tooele Valley, is usually free from an injurious quantity of salts in the surface foot. On the other hand, the second foot is usually, and the third and fourth feet are almost invariably, highly saline. In places where the surface foot contains much salts the plants of Kochia are scattered and stunted.

There is some evidence that the presence of Kochia vegetation, although in the great majority of cases associated with a strongly saline subsoil, does not invariably indicate such a condition. In the upper part of Tooele Valley an island of Kochia (Pl. XLIII, fig. 2) several acres in extent, in the midst of the sagebrush zone, was found to be underlain at a depth of 30 inches by a gravelly hardpan. The soil just above this stratum contained only about 0.2 per cent of readily soluble salts. It would seem that here the presence of hardpan rather than of salts had caused the Artemisia to give place to Kochia.

The conclusion seems warranted that the presence of the Kochia association to the exclusion of sagebrush is determined by the occurrence of 1 or at most 2 feet of soil free from an excess of salts, underlain by a subsoil which is strongly saline or which for some other reason is unfavorable to deep penetration of roots.

Summary of Physical Conditions.—In Tooele Valley the land occupied by the Kochia association is distinguished from that occupied by the sagebrush association by its finer texture, its tendency to puddle at the surface and, hence, resist the penetration of water, and its higher moisture-holding capacity, and also by the limitation of the depth in which the roots can freely develop to not more than 24 inches, the obstacle to deeper penetration being usually the high salt content of the subsoil.

Adaptations to Physical Conditions

Since *Kochia vestita* is the only very important species of the Kochia association, the structure of this plant alone need be considered in its

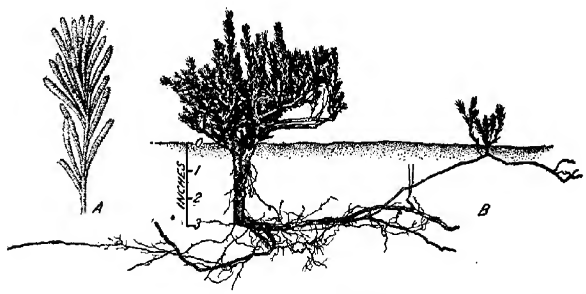


Fig. 7.—*Kochia vestita*: *A*, Detail, showing the narrow, hairy leaves; *B*, a plant showing the shallow root system and the propagation by root shoots.

relations to the physical conditions. The underground portion of the plant (fig. 7) is well adapted to the comparatively small depth of soil from which the total supply of water must be obtained. *Kochia vestita* spreads by means of long, slender-branching root shoots, which extend almost horizontally for distances of 10 feet or more, and often at a depth of only 3 inches from the surface of the soil. At intervals clusters of vertical shoots are sent up, and, hence, the plants above ground appear as isolated, unconnected clumps. In typical portions of this association the feeding roots are limited to the first 12 to 18 inches of the soil, the depth which is usually free from excessive quantities of alkali salts.

At one point where the root distribution was studied with special care, living roots were traced to a depth of about 18 inches, and at that depth the soil contained 0.9 per cent of salts, while at a depth of about 21 inches there was 1.6 per cent. Below this depth traces of dead roots were observed. Excavation at another point, where the first 6 inches

of the soil contained about 0.15 per cent of salts, the second 6 inches 0.36 per cent, and the second foot 1.2 per cent, showed only dead roots below the depth of 12 inches. A possible explanation of these circumstances would be that in some past period of exceptionally heavy rainfall the salt had been washed down to an unusually low depth and that the growth of the roots had kept pace. In subsequent years an upward movement of the salts would have resulted in the death of the deeper roots.

The total quantity of water available for growth in Kochia land is probably less than in any other type of land in the valley. The quantity of organic matter produced is also less, and although the plants often remain alive throughout the greater part of the summer the total quantity of water transpired is necessarily small.

Poa sandbergii, the only other abundant species of this association, is a shallow-rooted grass, which ripens its seeds and withers to the ground early in the summer. It is clearly dependent upon the moisture available in the surface soil.

Effects of Disturbing Factors: Successions

Where Kochia land has been plowed so as to completely destroy the original vegetation and subsequently has been abandoned, the reestablishment of the Kochia probably takes place rather slowly. When the "breaking" has been less thorough and a few plants have been left alive, the reestablishment of the Kochia proceeds more rapidly. The intervening stage of annual weeds or of Gutierrezia, such as occurs when the vegetation has been removed from sagebrush land, apparently does not follow after breaking on Kochia land.

Grazing is general in Tooele Valley, where many sheep are wintered. Kochia land is especially suitable for pasturage, being relatively level and free from spiny shrubs. The Kochia plants themselves are usually not much injured by grazing, but the associated grass (*Poa sandbergii*) is eaten to the ground and is often almost wholly eradicated.

Variations from the Typical Association

Kochia with Sagebrush.—As was pointed out above, *Artemisia tridentata* penetrates Kochia areas along drainage channels and in other places where the soil-moisture conditions are more favorable and the salt content smaller than in typical Kochia land. When associated with sagebrush, the plants of Kochia are much larger and more vigorous than where this plant occurs in the pure association.

Kochia with Shadscale.—On the lower edge of the Kochia zone plants of shadscale appear, scatteringly at first, then in greater numbers, until finally the two species are found mingled together in approximately equal proportions over large areas. The shadscale, being much the larger plant, is alone visible at a short distance, even where it is numerically

not superior to the Kochia. The line of demarkation between the Kochia and shadscale associations is never a sharp one, and this conforms with the fact that the physical conditions indicated by the two types of vegetation are similar.

SHADSCALE ASSOCIATION

TOPOGRAPHICAL RELATIONS

The shadscale association is one of the most characteristic and important of the Great Basin region In the Tooele Valley (see map, Pl. XLII) it occupies a wide belt across the middle part of the valley, just below the Kochia belt, extending farthest northward along the base of the Stansbury Range. The dominant species as a constituent of the greasewood-shadscale association extends to the edge of the grass flats and beyond that area occupies ridges and hummocks on the salt flats which border Great Salt Lake. Isolated small patches of pure shadscale also occur within the area mapped as salt flat.

BOTANICAL COMPOSITION

The most abundant plant of this association is the species of saltbush (*Atriplex confertifolia*) which is commonly known as shadscale, from the shape of the scalelike bracts which envelop the fruits. (See fig. 9.) The number of associated species is much smaller than in the sagebrush association, and those which occur are usually represented by fewer individuals. The plants which were noted as occurring in this association are the following:

PERENNIAL SPECIES

Poa sandbergii Vasey	*Opuntia* sp.
Sitanion minus Smith	*Lappula occidentalis* (Wats.) Greene
Allium acuminatum Hook.	*Artemisia spinescens* Eat.
Atriplex confertifolia (Torr.) Wats.	*Chrysothamnus marianus* Rydb.
Eurotia lanata (Pursh) Moq.	*Tetradymia glabrata* Gray
Kochia vestita (Wats.) A. Nels.	*Tetradymia spinosa* H. and A.

ANNUAL AND BIENNIAL SPECIES

Bromus marginatus seminudus Shear	*Cryptanthe multicaulis* A. Nels.
Lepidium jonesii Rydb.	*Oreocarya shantzii* Tidestrom
Thelypodium elegans Jones	*Townsendia watsonii* Gray

APPEARANCE

The general appearance of the shadscale association (Pl. XLVII, fig. 1) is due almost entirely to the dominant species. *Atriplex confertifolia* as found in Tooele Valley is a rounded bush, usually about 18 inches in height and also in diameter, with rigid, spiny branches and harsh dry-looking foliage. (See fig. 9.) The individual plants tend to form low hummocks, the soil immediately about them being held by the partly

recumbent, twisted branches, while the bare ground between is subject to blowing.

The prevailing color is a dull grayish brown, turning to reddish brown in autumn. Plants growing in depressions, where the moisture conditions are exceptionally favorable, have a bluish hue. Viewed from a short distance the association gives the impression of extreme monotony and lifelessness.

The distribution of the plants is indicated in figure 8, which represents a quadrat 10 meters square, in a typical portion of this association. Where the conditions are most favorable, the plants have a fairly vigorous appearance and cover somewhat more than half the ground, the stand being frequently more dense than is usually the case in the sagebrush association. In much the greater part of the area, however, the proportion of bare ground is greater and the plants seem to be having a hard struggle to maintain life, many of their branches being dead or dying. (Pl. XLVII, fig. 1.) No other vegetation in this valley gives the impression of being so nearly conquered by the environment. Even the few species which grow on the salt flats have the appearance of finding their habitat more congenial.

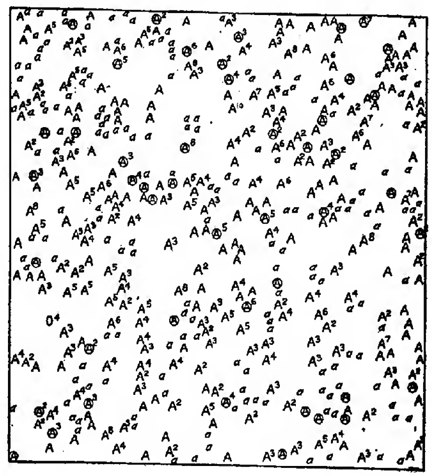


FIG. 8.—A representative 10-meter quadrat of the shadscale association, showing the location of each individual plant of *Atriplex confertifolia* (*A*), the only woody species present, and of *Opuntia* sp. (*O*). The figures show the number of main stems and, hence, indicate the size of the plant. A circle around the letter indicates that the plant is dead. Seedlings of Atriplex are indicated by the small *a*. The annual grass Bromus (not indicated on the quadrat) was very abundant around the Atriplex bushes.

The associated species contribute scarcely at all to the general appearance of the association. Annuals are of very minor importance. The small shrubs of the family Compositæ which occur here and there are too few in number of individuals and are too much like the shadscale in habit of growth and dullness of color to influence materially the aspect of the vegetation. *Kochia vestita* is associated with the shadscale in extensive areas where the vegetation appears otherwise typical of the present association. The much smaller size of the Kochia plants makes them inconspicuous.

Physical Conditions Indicated

The conditions in shadscale land as regards moisture and salt content of the soil are shown in Table X, which gives the results of various borings in typical areas.

Table X.—*Shadscale association: Moisture conditions and salt content of the soil in typical areas.*[1]

Item.	Depth of soil (foot).	Date of collection.								
		June.				July.	August.			
		3	7	26	26	5	5	6	6	Average.
No. of sample	......	17	34	54	55	56	72	108	117	
Moisture equivalent	1	......	......	24.2	23.4	21.7	22.4	......	......	22.9
	2	......	......	31.4	28.8	36.1	27.9	......	......	31.0
	3	......	......	34.0	32.4	35.8	35.8	......	......	34.5
	4	......	......	33.7	32.6	29.5	26.9	......	......	30.6
Wilting coefficient	1	......	......	13.1	12.7	11.8	12.2	......	......	12.4
	2	......	......	17.0	15.6	19.6	15.1	......	......	16.8
	3	......	......	18.5	17.6	19.5	19.5	......	......	18.7
	4	......	......	18.3	17.7	16.0	14.6	......	......	16.6
Moisture content above or below wilting coefficient	1	......	......	−6.5	−5.9	−4.7	−5.2	......	......	−5.6
	2	......	......	−4.5	−5.2	−5.2	−5.8	......	......	−5.2
	3	......	......	−5.1	−4.8	−5.2	−4.8	......	......	−5.0
	4	......	......	−4.6	−3.6	−6.6	−7.1	......	......	−5.5
Salt content	1	0.10	0.05	.05	.07	.06	.06	0.05	0.12	.07
	2	.36	.05	.44	.29	.22	.27	.42	.54	.32
	3	.40	.22	.88	.82	.88	1.06	1.14	.88	.78
	4	......	......	.88	.94	.88	.80	......	1.14	.93

[1] All data in this table are stated in percentages of the dry weight of the soil. The moisture contents with a plus sign (+) represent moisture available for growth (above the wilting coefficient), while those with a minus sign (−) represent a corresponding deficit of available moisture (below the wilting coefficient).

Comparison with the corresponding data in Table IX shows little difference in the physical conditions of the shadscale and Kochia land. The surface foot of soil in the shadscale association usually contains more gravel and is of somewhat lighter texture, as indicated by the somewhat lower average moisture equivalent. This, together with the rougher surface of the land, would indicate more favorable conditions for the penetration of water.[1] On the other hand, the second, third, and fourth feet show a more constant and more pronounced deficit of available moisture than is the case in Kochia land. At first glance this would seem to confute the assumption that the conditions for the penetration of water are better than on Kochia land, but it must be remembered that in shadscale land, which supports much the heavier vegetation, the loss of water by transpiration must be greater.

The average salt content at all depths down to 4 feet is somewhat smaller in shadscale than in Kochia land, but in this respect the difference between the two types is of small importance.

[1] In some parts of the shadscale area, especially where *Kochia vestita* is abundant, a tendency to the formation of hardpan at a depth of about 24 inches was noted, but this condition appears to be exceptional in Tooele Valley.

An 8-foot boring made in a portion of the shadscale area where *Kochia vestita* was also abundant gave interesting results as regards the salinity of the soil at greater depths than were reached by any of the borings included in Tables IX and X. The percentage of salt contents at the successive 1-foot depths were 0.10, 0.79, 1.02, 0.98, 0.92, 0.88, 0.94, and 1.02, which indicates a very uniform condition as regards salt content of the soil below the second foot and to an unknown depth.

The differences in the averages for each physical factor as given in Tables IX and X scarcely seem of sufficient magnitude to explain the separate occurrence of *Atriplex confertifolia* and *Kochia vestita* in distinct associations alternating over large areas, especially when we note that some of the borings in typical portions of each association show almost identical physical conditions. It is not surprising therefore that the line of contact between the two associations is a vague one and that the two species mingle on equal terms over areas of considerable extent. Yet there is a possible explanation for the alternation of these two types which is not brought out by the data given in these tables. In Kochia land, because of the less favorable conditions for penetration, the seasonal total of available moisture may not be sufficient to support a stand of shadscale in competition with Kochia.

The distribution of *Atriplex confertifolia* appears to be limited toward the upper end of the valley by the occurrence of light, easily permeable soil which is free from an excess of salts to a depth of 3 feet or more. In such land shadscale can not compete with sagebrush. Toward Great Salt Lake it is confined to the drier, better drained land of the hummocks and ridges and is excluded from the flats where the soil is excessively saline and is wet to the surface during much of the year.

Areas of very limited extent are found here and there in which the shadscale plants are much larger than the average and have a green, thrifty appearance, with a notable absence of dead wood. In such spots—generally obvious depressions—the soil conditions are more favorable than in most of the shadscale area, the salt content being lower and the moisture content higher. The results of a boring in one such spot, made on July 13, are given in Table XI.

TABLE XI.—*Salt content and moisture conditions of the soil in a spot where Atriplex confertifolia was exceptionally large and healthy.*[1]

Depth (feet).	Salt content.	Wilting coefficient.	Moisture content above or below wilting coefficient.
1	0.06	20.5	−10.1
2	.05	17.4	−2.0
3	.09	18.3	+2.8
4	.09	18.1	0.0

[1] All data in percentages of the dry weight of the soil.

The low salt content throughout the 4 feet, the relatively high wilting coefficients, and the presence so late in the summer of available moisture in the third foot are worthy of note.

SUMMARY OF PHYSICAL CONDITIONS.—The presence of the typical shadscale association as it occurs in Tooele Valley indicates usually (1) a soil of finer texture, having a higher moisture equivalent than in sagebrush land; (2) a deficit in midsummer of moisture available for plant growth; (3) a high salt content of the soil below the depth of 1 or 2 feet;[1] and (4) as compared with land occupied by the Kochia associa-

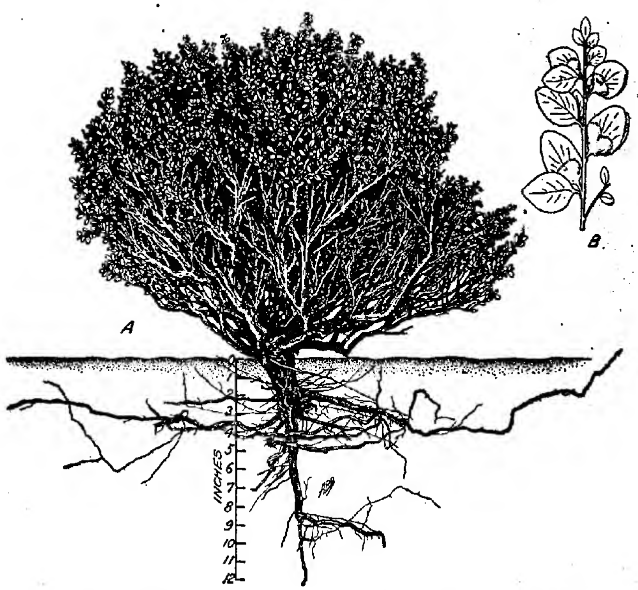


FIG. 9.—*Atriplex confertifolia* (shadscale): *A*, A typical plant, showing the thick, vertical taproot and the widespreading lateral roots; *B*, detail of a fruiting branch, showing the shape of the leaves and of the bracts or scales, which envelop the fruits.

tion, a somewhat lighter and more gravelly texture in the first foot and a much more uneven surface—conditions which probably result in better penetration and, hence, in a larger seasonal total of water available for plant growth than on Kochia land.

ADAPTATIONS TO PHYSICAL CONDITIONS

The dominant species, *Atriplex confertifolia*, need alone be considered in this connection. As shown in figure 9, this plant has a well-developed

[1] In localities outside of Tooele Valley shadscale is not confined to areas having a saline subsoil, but is also found on dry, gravelly soils where the moisture conditions are apparently too extreme for sagebrush.

taproot, its root system being, therefore, very different from that of *Kochia vestita*.

The roots of shadscale, although by no means so deep as those of *Artemisia tridentata*, doubtless as a rule penetrate and obtain water from a greater depth of soil than do the roots of Kochia.[1] This would help to explain the fact that, notwithstanding the more favorable conditions for penetration of water, the deficit during periods of drought of moisture available for growth in the second, third, and fourth feet is normally greater in shadscale than in Kochia land.

The moribund appearance in 1912 of the shadscale plants in most of the area covered by this association in Tooele Valley points to the conclusion that in years of not more than average rainfall the moisture supply is inadequate. Thus, in 1912 the moisture available for growth had been exhausted to a depth of 4 feet, and the plants had begun to shed their leaves before the end of June. Apparently, with the normal thickness of stand in this association, the older individual plants can not obtain sufficient water to maintain life in all parts of their bodies. The branches are in active competition and the plant as a whole remains alive only by sacrificing some of its members. The death of some of the branches in almost every plant which has passed the seedling stage reduces by so much the transpiring surface and results in a proportionate economy of the scanty moisture available to each individual. To an even greater degree than *Artemisia tridentata* this plant has the faculty of remaining during a great part of the year in a nearly dormant condition, while retaining some of its foliage.

Effects of Disturbing Factors: Successions

The exact stages in the revegetation of shadscale land from which the original plant cover has been removed by fire or by the plow remain to be worked out. There is evidence, however, that *Gutierrezia sarothrae* forms an important stage in these successions. A large area near the center of Tooele Valley is covered with an almost pure growth of this small, yellow-flowered plant of the Compositæ. While a part of this tract was probably once occupied by sagebrush, the greater portion occurs in the midst of the shadscale belt and has a strongly saline subsoil.[2]

[1] Nevertheless, the Atriplex roots do not develop well in a strongly saline subsoil. Thus, at a boring where the first foot of the soil contained 0.1 and the second 0.8 per cent of salts, few living roots were found below the depth of 12 inches.

[2] This plant shows marked adaptability to varying soil conditions. In areas having a saline subsoil, which were presumably covered originally with shadscale, the plants of Gutierrezia are scattered and small and have a superficial root system, while in nonsaline areas, where sagebrush was probably the original vegetation, the stand is denser, the plants are larger, and a good taproot is developed.

Variations from the Typical Association

The shadscale area in Tooele Valley comes into contact on its upper limit with the sagebrush and the Kochia associations and on its lower limit with the greasewood-shadscale association. In each case mixed or transitional communities result. The conditions under which shadscale mingles with sagebrush and with Kochia have been discussed on preceding pages. The transition to the greasewood-shadscale association, which is a very gradual one, will be treated in connection with the latter association.

GREASEWOOD-SHADSCALE ASSOCIATION

Topographical Relations

The area occupied by the greasewood-shadscale association forms an interrupted belt (see map, Pl. XLII) across the valley between the areas occupied by the shadscale association, and by the grass flats, respectively. It also covers the low ridges and hummocks which alternate with the basinlike depressions and flats near the shore of Great Salt Lake (Pl. XLIII, fig. 1, and Pl. XLVII, fig. 3). In general, it occupies all areas where the water table is sufficiently high to make moist soil accessible to the deep-rooting greasewood and where at the same time 1 or 2 feet of the surface soil are sufficiently dry to permit the growth of shadscales Where the water table is too low this association gives place to the pure shadscale. On the other hand, as the soil becomes wet nearer and nearer the surface, the shadscale gradually disappears and at the edge of the grass flats greasewood associates with *Allenrolfea occidentalis* and *Suaeda moquinii* instead of with *Atriplex confertifolia*.

Botanical Composition

This type of vegetation is dominated by two shrubby species, greasewood (*Sarcobatus vermiculatus;* see fig. 10, p. 404) and shadscale (*Atriplex confertifolia;* fig. 9, p. 398). In typical areas these plants intermingle in approximately equal numbers, but on the highest ground (Pl. XLVII, fig. 2) shadscale is strongly predominant, while on the lowest land where this association occurs greasewood is the more abundant. *Kochia vestita* is abundant in much of the area occupied by this association, but the plants are so small in comparison with the two dominant species that they do not affect the general appearance of the vegetation. In spots of limited size greasewood and Kochia are associated, shadscale being absent. The soil conditions in such spots do not differ materially from those of the typical greasewood-shadscale association. Few other species are found, and of these the number of individuals is usually small. The following list includes all species noted as occurring in the greasewood-shadscale association:

PERENNIAL SPECIES

Elymus condensatus Presl	*Sarcobatus vermiculatus* (Hook.) Torr.
Poa sp. (*P. sandbergii* Vasey?).	*Suaeda moquinii* (Torr.) A. Nels.
Sitanion minus Smith	*Suaeda intermedia* Wats.
Atriplex confertifolia (Torr.) Wats.	*Lappula occidentalis* (Wats.) Greene
Atriplex nuttallii Wats.	*Gutierrezia sarothrae* (Pursh) B. and R.
Kochia vestita (Wats.) A. Nels.	*Tetradymia nuttallii* T. and G.

ANNUAL AND BIENNIAL SPECIES

Bromus tectorum L.	*Sophia pinnata* (Walt.) Howell
Erysimum asperrimum (Greene) Rydb.	*Machaeranthera canescens* (Nutt.) Gray

The local distribution of most of these plants varies greatly within the area occupied by the association, probably because of the great diversity in the depth to permanent moisture and at which the subsoil becomes strongly saline.

APPEARANCE

This type of vegetation is less monotonous in its appearance than the sagebrush, Kochia, and shadscale associations, owing to the strong contrast in color and usually in size between the two dominant species. (Pl. XLVII, fig. 2.) Greasewood has a bright-green color, changing to yellowish later in the season, and appears dark when photographed against the sun. Shadscale, on the other hand, has a dull brownish gray hue. The former plant often reaches a height of 4 or 5 feet, while the latter seldom exceeds 2 feet.

At the highest elevations occupied by this association there is sufficient moisture for the growth of greasewood only along drainage channels, and the general surface of the land is covered with pure shadscale. Somewhat farther toward Great Salt Lake plants of greasewood are scattered among the shadscale, although much less numerous than the latter. Finally near the borders of the grass flats and on the ridges and hillocks which intersect the salt flats the two species grow side by side on more or less equal terms, and their colors blend when the vegetation is viewed from a short distance.

PHYSICAL CONDITIONS INDICATED

The soil moisture and salinity conditions, which characterize typical portions of the land occupied by this association, are indicated by the data in Table XII. Comparison with Table X will bring out the differences between this environment and that of the pure shadscale association.

TABLE XII.—*Greasewood-shadscale association: Moisture conditions and salt content of the soil in typical areas.*[1]

Item.	Depth of soil (feet).	Date of collection.							
		June.			July.				
		4	7	27	3	3	6	29	Average.
No. of sample		19	35	63	66	69	75	98	
Moisture equivalent	1	22.0	......	26.5	26.5	26.1	28.5	15.5	24.1
	2	22.9	......	30.8	34.2	32.2	24.8	14.7	26.6
	3	13.3	......	35.3	31.5	33.5	20.8	22.2	26.1
	4	27.0	......	30.2	31.5	31.3	17.5	24.2	26.9
Wilting coefficient	1	11.9	......	14.4	14.4	14.2	15.5	8.4	13.1
	2	12.4	......	16.7	18.6	17.5	13.5	8.0	14.4
	3	7.2	......	19.2	17.1	18.2	11.2	12.1	14.2
	4	14.7	......	16.4	17.1	17.0	9.5	13.1	14.6
Moisture content above or below wilting coefficient	1	− .1	......	− .5	− 4.4	− 4.4	− .3	− 4.7	− 2.4
	2	+ 4.5	......	+ 6.1	+ 4.1	+ 3.2	+ 3.1	+ .4	+ 3.6
	3	+ 3.5	......	+10.2	+ 4.1	+ 4.3	+ 8.8	+ 3.3	+ 5.7
	4	+ 1.0	......	+ 8.4	+ 3.9	+ 2.8	+13.1	+ 2.5	+ 5.3
Salt content	1	.08	0.05	.64	.27	1.54	.61	.23	.34
	2	.61	.38	1.24	.54	1.10	.61	.60	.72
	3	.62	.82	1.85	.65	1.36	.68	1.25	1.03
	4	1.30	.94	1.36	1.05	1.48	.76	......	1.15
	5	1.96	1.20	......	......	......	......	......	1.58

[1] All data in this table are stated in percentages of the dry weight of the soil. The moisture contents with a plus sign (+) represent moisture available for growth (above the wilting coefficient), while those with a minus sign (−) represent a corresponding deficit of available moisture (below the wilting coefficient).

SOIL MOISTURE.—The moisture-holding capacity of the soil, as indicated by the moisture equivalent, is somewhat higher in the first foot, but is lower in the second, third, and fourth feet than in the shadscale association. It is significant that moisture available for the growth of plants was present in considerable quantity during the months of June and July in all but the surface foot in the greasewood-shadscale association, while in the shadscale association during the same months there was a marked deficit of available water to a depth of 4 feet. The relatively high moisture content is correlated with the relatively slight elevation above the level of water in the lake and with a consequently high ground-water table.

SALINITY.—The average salt content of each of the first 4 feet of the soil is much higher than in the shadscale association, the difference being especially marked in the second foot, which contains, on the average, as much salts as does the third foot in land occupied by pure shadscale.

SUMMARY OF PHYSICAL CONDITIONS.—In Tooele Valley the presence of typical greasewood-shadscale vegetation indicates soil conditions as follows: (1) A fairly high moisture equivalent; (2) the surface foot well drained and usually dry during the summer; (3) moisture available for the growth of plants present throughout the summer at a comparatively slight depth; (4) a high salt content from the second foot downward and often in the surface foot as well.

ADAPTATIONS TO THE PHYSICAL CONDITIONS

The two dominant species have somewhat different soil requirements, and the land occupied by this association offers a combination of conditions which permits them to grow side by side. Greasewood prefers an ample and permanent supply of moisture within reach of its roots, and its strong, deeply penetrating taproot (fig. 10) enables it to reach moisture in places where the surface soil is dry and the ground-water table is at a considerable depth. This plant can live in soil which is moist to the surface, although under such conditions the plants are never as large and vigorous as where a higher elevation and a subsoil of light texture afford better drainage. Shadscale, on the other hand, does not thrive with its roots in wet soil, and its presence is usually a reliable indication that at least the surface foot is dry during the greater part of the summer.

Greasewood (*Sarcobatus vermiculatus*) grows in a greater variety of habitats than any other flowering plant of the Tooele Valley. It was found in one place or another in company with the dominant species of all of the leading associations. In much the greater part of its range in the valley greasewood is associated with shadscale, but there are exceptions to this rule. The largest and thriftiest looking greasewood plants[1] grew on the summits of dunes of pure sand, together with sagebrush, juniper, Eriocoma, Abronia, Eriogonum, Psoralea, and other characteristic plants of the sand-hill mixed association. Shadscale is absent from this community. At the other extreme greasewood occurs in company with Allenrolfea in land which is too wet and saline for the growth of shadscale. The widely different conditions in these two environments are indicated by the data in Table XIII.

TABLE XIII.—*Moisture equivalent and salt content of the soil where Sarcobatus vermiculatus occurred—on the sand hills and with Allenrolfea.*[1]

Depth (feet).	Moisture equivalent.		Salt content.	
	On sand hills.	With Allenrolfea.	On sand hills.	With Allenrolfea.
1	6.2	31.0	0.09	2.16
2	6.8	37.3	.08	2.08
3	6.1	27.7	.14	1.76
4	7.0	25.9	.16	1.25

[1] All data in percentages of the dry weight of the soil.

The growth of greasewood on the sand hills makes it evident that this plant is not an infallible alkali indicator, although in the great majority of cases its occurrence is associated with an excess of salts in the soil, and in its ability to endure the presence of alkali it is surpassed by few other

[1] The individual alongside the boring made in the sand hills (see Table XIII) was 6 feet high, 10 feet across, and had several stems which were from 1 to 2 inches in diameter at the surface of the ground.

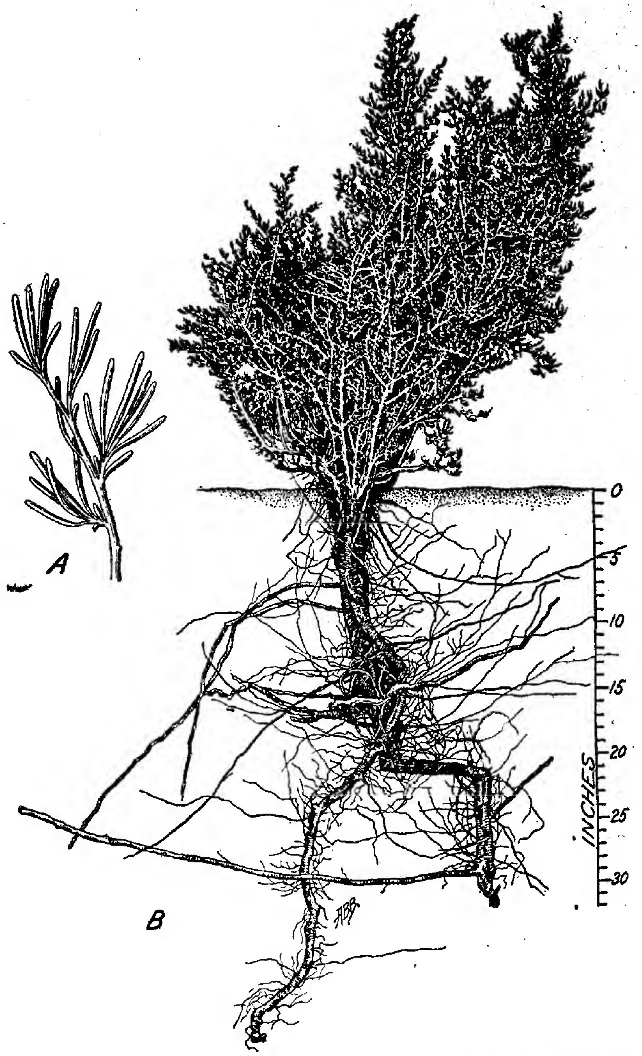


FIG. 10.—*Sarcobatus vermiculatus* (greasewood): *A*, Detail showing the narrow, rather fleshy leaves; *B*, a plant showing the excellent root development. The large, deeply penetrating taproot is characteristic of this species.

flowering plants.[1] A condition which is almost always correlated with the presence of greasewood is a permanent supply of moisture available for growth within the depth of soil penetrated by its roots.

GRASS-FLAT COMMUNITIES[2]

Topographical Relations

The grass-flat of vegetation occurs in an interrupted belt (see map, Pl. XLII), which crosses the northern part of the valley and lies between the area occupied by the main body of the greasewood-shadscale association and the salt flats. It covers a gently sloping or nearly level expanse and appears to be lower in elevation than some of the ridges and hillocks situated between it and the shore of the lake. The area is thus somewhat analogous to a coastal lagoon and may have had a similar origin. It is characterized during the greater part of the year by a very moist condition of the soil, due probably in part to seepage.

Appearance and Botanical Composition

The vegetation of the grass flats shows considerable diversity. Several plant communities can be distinguished, although the boundaries are rarely very sharp. The two most important of these are characterized by the dominance of (1) tussock grass, or purple top (*Sporobolus airoides*), and rabbit brush (*Chrysothamnus graveolens glabrata*), and (2) salt grass (*Distichlis spicata*). The rabbit brush is also frequently associated with greasewood (*Sarcobatus vermiculatus*), especially along lines of contact between greasewood-shadscale areas and the grass flats. For the most part the vegetation of the grass flats is distinctly halophytic in character, but in limited areas around springs and flowing wells it resembles that of an ordinary nonsaline meadow.

A list of the species which were noted as composing the grass-flat vegetation follows:

PERENNIAL SPECIES

Triglochin maritima L.
Triglochin palustris L.
Distichlis spicata (L.) Greene
Poa nevadensis Scribner
Puccinellia airoides (Nutt.) Wats.
Spartina gracilis Trin.
Sporobolus airoides Torr.
Juncus balticus Willd.
Iris sp. (probably *I. missouriensis* Nutt.).
Halerpestes cymbalaria (Pursh) Greene
Dodecatheon sp.
Glaux maritima L.
Aster pauciflorus Nutt.
Chrysothamnus graveolens glabrata (Gray) A. Nels.
Crepis glauca (Nutt.) T. and G.
Iva axillaris Pursh

[1] At Grand Junction, Colo., young seedlings of greasewood were found growing where the soil to a depth of 2 inches, which was about the limit to which their roots had penetrated, gave a specific resistance of 36 ohms, indicating the presence of at least 2.5 per cent of salts.

[2] The ecological status of the vegetation of the grass flats can not be determined until further investigations in the Great Basin region shall have been made. For the present, therefore, it seems advisable to use the general term "community" in referring to these types.

ANNUAL AND BIENNIAL SPECIES

Hordeum jubatum L.	*Melilotus alba* Desv.
Salicornia rubra A. Nels.	*Erythraea arizonica* (Gray) Rydb.
Suaeda erecta (Wats.) A. Nels.	*Orthocarpus tolmiei* H. and A.
Atriplex spatiosa A. Nels.	*Carduus scariosus* (Nutt.) Heller
Cleome serrulata Pursh	

PHYSICAL CONDITIONS INDICATED

Reference to Tables XIV and XV shows that there is much variation in the moisture and salinity conditions of the grass-flat area, but, broadly speaking, the soils are characterized by (1) a high moisture-holding capacity, ascribable partly to the fine texture and partly to the large quantity of organic matter present, (2) the presence near the surface and usually throughout the summer of moisture available for growth (above the wilting coefficient), and (3) a salt content sufficiently high to be injurious to many crop plants. The soils under the salt-grass community (Table XV), while usually much more saline than under the Sporobolus-Chrysothamnus community (Table XIV), have an average salinity inferior to that of the salt flats (Tables XVI and XVII).

SPOROBOLUS-CHRYSOTHAMNUS COMMUNITY

The Sporobolus-Chrysothamnus community (Pl. XLVIII, fig. 3) covers a large part of the grass-flat area in Tooele Valley. In places one or the other of the dominant species occurs where the other is absent, but they are more often closely associated. Salt grass (*Distichlis spicata*) is also usually more or less abundant in this community.

Tussock grass (*Sporobolus airoides*) forms coarse mats, which are as a rule closely grazed by animals. In late summer the feathery purple panicles of this grass are a characteristic feature of the vegetation of the grass flats in such areas as are not grazed. The rabbit brush (*Chrysothamnus graveolens glabrata*) is a much-branched shrub, from 2 to 4 feet high, with whiplike slender branches having green bark and very small, narrow leaves. Its color is bright green, modified in late summer by the numerous small heads of yellow flowers which resemble those of goldenrod. The physical conditions where this community occurs are indicated by the data given in Table XIV.

TABLE XIV.—*Sporobolus-Chrysothamnus community: Salt content and moisture conditions of the soil in typical areas.*[1]

Item.	Depth of soil (feet).	Date of collection. June 4.	July 29.	August 26.								Average.
No. of sample	....	18 SC.	100 C.	S.	S.	S.	SC.	SC.	SC.	C.	C.	
Salt content	1	0.12	0.25	0.85	0.45	0.35	0.20	0.20	0.25	0.35	0.20	0.33
	2	.46	.45	.40	.40	.60	.25	.35	.45	.65	.45	.44
	3	.53	.58	.20	.20	.50	.20	.30	.15	1.05	.35	.40
	4	.26	.30	.20	......	......	.15	......	......	......	......	.23
	5	.14	......	......	......	......	......	......	......	......	......	......
Moisture equivalent	1	34.0	29.5	......	......	......	......	......	......	......	......	......
	2	29.1	35.3	......	......	......	......	......	......	......	......	......
	3	34.3	46.6	......	......	......	......	......	......	......	......	......
	4	26.4	36.7	......	......	......	......	......	......	......	......	......
	5	31.6	......	......	......	......	......	......	......	......	......	......
Wilting coefficient	1	18.5	16.0	......	......	......	......	......	......	......	......	......
	2	15.8	19.2	......	......	......	......	......	......	......	......	......
	3	18.6	25.3	......	......	......	......	......	......	......	......	......
	4	14.3	19.9	......	......	......	......	......	......	......	......	......
	5	17.1	......	......	......	......	......	......	......	......	......	......
Moisture content above or below wilting coefficient	1	−0.8	+4.5	......	......	......	......	......	......	......	......	......
	2	+4.4	+11.4	......	......	......	......	......	......	......	......	......
	3	+5.8	+25.6	......	......	......	......	......	......	......	......	......
	4	+9.8	+14.3	......	......	......	......	......	......	......	......	......
	5	+6.1	......	......	......	......	......	......	......	......	......	......

[1] All data in this table are stated in percentages of the dry weight of the soil. The moisture contents with a plus sign (+) represent moisture available for growth (above the wilting coefficient), while those with a minus sign (−) represent a corresponding deficit of available moisture (below the wilting coefficient). The unnumbered borings were made on Aug. 26, 1913, and the letters indicate whether the vegetation was dominated by Sporobolus without Chrysothamnus (S), Sporobolus with Chrysothamnus (SC), or Chrysothamnus without Sporobolus (C).

SALT-GRASS (DISTICHLIS) COMMUNITY

Distichlis spicata, well known as salt grass throughout the western United States, is a low-growing, harsh-leaved grass which spreads by creeping rootstocks. It tends to form a heavy sod, especially where the land is grazed, and under such conditions this plant is very efficient in adding humus to the soil.

Salt grass is more or less abundant in all parts of the grass flats and also penetrates the salt flats (Pl. XLVII, fig. 3), where in some places it associates scatteringly with Allenrolfea and in other places forms dense mats. In the wetter portions of the grass flats salt grass is the principal component of a meadowlike vegetation, with *Juncus balticus*, *Suaeda erecta*, *Puccinellia airoides*, and *Glaux maritima* as important associates and with numerous other species occasionally present.

The conditions as regards soil moisture and salinity at borings where this community occurs are stated in Table XV.

TABLE XV.—*Salt-grass community: Moisture conditions and salt content of the soil in typical areas.*[1]

Item.	Depth of soil (feet).	Date of collection.						
		June.	July.				August.	Average.
		4	6	12	12	29	6	
No. of sample	....	20	73	83	84	101	109	
Moisture equivalent	1	28.5	28.4	....	30.9	48.9	....	34.1
	2	32.6	17.1	....	22.6	54.9	....	31.8
	3	35.1	19.4	....	13.2	65.8	....	33.3
	4	....	36.1	....	....	62.2	....	49.1
Wilting coefficient	1	15.5	15.4	....	16.5	26.6	....	18.5
	2	17.7	9.3	....	12.3	29.6	....	17.3
	3	19.1	10.5	....	7.2	35.8	....	18.1
	4	....	19.6	....	....	33.8	....	26.7
Moisture content above or below wilting coefficient	1	+ 3.1	+ 8.9	....	....	+16.7	....	+ 9.6
	2	+ 9.5	+ 6.9	....	....	+24.2	....	+13.5
	3	+11.5	− 1.3	....	....	+24.2	....	+11.4
	4	....	− 4.5	....	....	+32.2	....	+13.8
Salt content	1	.25	2.30	0.57	.53	.59	2.18	1.07
	2	.56	1.64	.80	.24	.72	1.85	.97
	3	.76	1.36	.60	....	.34	....	.76
	4	1.02	1.14	.24	....	.18	....	.64

[1] All data in this table are stated in percentages of the dry weight of the soil. The moisture contents with a plus sign (+) represent moisture available for growth (above the wilting coefficient), while those with a minus sign (−) represent a corresponding deficit of available moisture (below the wilting coefficient).

SALT-FLAT COMMUNITIES[1]

TOPOGRAPHICAL RELATIONS

Along the margin of Great Salt Lake there is a belt of low land which varies in width from about 4 miles, near the axis of the valley, to a mere fringe on the east and west sides where the mountain ranges approach the lake shore. Much of this area (see map, Pl. XLII) is covered with water at times, but in summer presents a dazzling white surface due to the heavy crust of salts (Pl. XLIII, fig. 1, and Pl. XLVIII, fig. 1). These flats are divided into shallow basins of greater or less extent, separated by low ridges and hummocks. (See Pl. XLII, detail of vegetation west of Grants.) All but the lowest of these elevations are occupied by the greasewood-shadscale association (see foreground of Pl. XLIII, fig. 1), while the basins and flats when not altogether devoid of vegetation support a few extremely halophytic species (Pl. XLVIII, figs. 1 and 2), which occur either as scattered individuals or in crowded colonies.

The two environments are ecologically quite distinct, but it is impracticable to indicate on a map of the small scale used in Plate XLII the areas actually occupied by elevations and by depressions, with their respective types of vegetation. Greasewood occurs not only on the higher ridges in association with shadscale, but also on the lower hummocks and at the edges of the depressions, in association with Allenrolfea. Shadscale, on the other hand, is not found in the depressions, nor do the typical salt-flat species occur on the higher ridges.

[1] The ecological status of the salt-flat vegetation, like that of the grass-flat vegetation, can not be determined without more extensive investigation in the Great Basin region. In the present paper it seems advisable to use the general term "community" in referring to these types.

The vegetation of the flats and depressions comprises several communities, each characterized by the presence of a single species—*Allenrolfea occidentalis*, *Salicornia utahensis*, and *S. rubra*. The first of these is by far the most abundant and widely distributed. These three species appear to be the most salt resistant of the flowering plants of this region, taking possession of the land left bare by the recession of the lake as soon as its salt content has been reduced sufficiently from the point of saturation with the excessively saline lake water to permit the growth of any flowering plant.

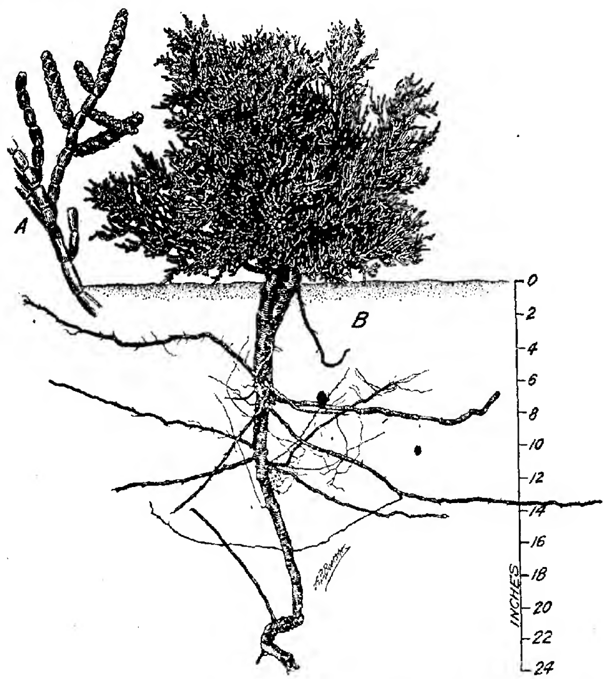


FIG. 11.—*Allenrolfea occidentalis*: *A*, Detail of a fruiting branch, showing the cylindrical, fleshy, practically leafless stems; *B*, a plant showing the large taproot and rather scanty lateral roots characteristic of this species.

ALLENROLFEA COMMUNITY

APPEARANCE AND BOTANICAL COMPOSITION.—The dominant species, *Allenrolfea occidentalis*, is a shrubby plant with numerous cylindrical, jointed, fleshy, practically leafless branches and a large taproot (fig. 11). In Tooele Valley it rarely exceeds a height of 2 feet. There is considerable variation in the habitat of this plant, but it develops most characteristically on low hummocks on the salt flats (Pl. XLVIII, fig. 1) and near the bases of the higher ridges, usually preferring a slightly

better drained and less saline soil than the species of Salicornia. In places, however, it is seen scattered over the surface of the flats, the dark brownish green tufts of Allenrolfea contrasting strikingly with the pure white of the saline incrustation. The thinness of the stand is shown in figure 12, which represents a typical 10-meter quadrat. Often, as shown in Plate XLVIII, figure 1, Allenrolfea forms a pure community. On higher and better drained ground, however, it is frequently associated with *Sarcobatus vermiculatus* and with *Suaeda moquinii*, while in the wetter depressions it often mingles with *Salicornia utahensis*. Plants of greasewood, when growing with Allenrolfea, are usually stunted and sickly looking.

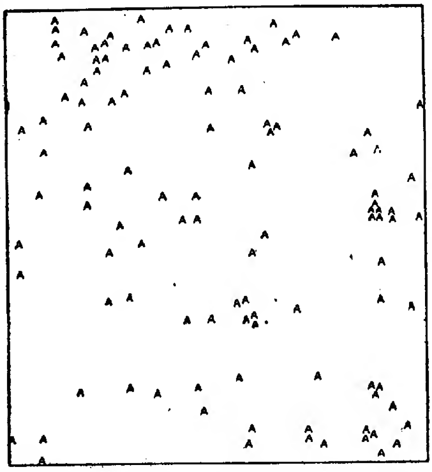


FIG. 12.—A representative 10-meter quadrat of the Allenrolfea community (salt-flat association), showing the location of each individual plant of *Allenrolfea occidentalis*, the only species present.

PHYSICAL CONDITIONS INDICATED.—The conditions as to soil moisture and salt content at all borings where Allenrolfea occurred are given in Table XVI.

TABLE XVI.—*Allenrolfea community: Moisture conditions and salt content of the soil in typical areas.*[1]

Item.	Depth of soil (feet).	Date of collection.										Average.
		June.		July.							Aug.	
		4	27	6	6	12	12	12	12	29	6	
No. of sample		21	64	73	76	80	81	82	84	97	109	
Moisture equivalent.	1	......	31.1	28.4	25.5	24.4	......	......	26.7	24.6	......	26.7
	2	......	37.4	17.1	25.6	19.3	......	......	13.2	28.2	......	23.4
	3	......	27.9	19.4	26.0	17.3	......	......	......	18.5	......	21.8
	4	......	26.0	36.1	30.2	......	......	......	......	29.5	......	30.4
Wilting coefficient	1	......	16.9	15.4	13.9	13.2	......	......	14.5	13.4	......	14.5
	2	......	20.3	9.3	13.9	10.5	......	......	7.2	15.3	......	12.7
	3	......	15.1	10.5	14.1	9.4	......	......	......	10.0	......	11.8
	4	......	14.1	19.6	16.4	......	......	......	......	16.0	......	16.5
Moisture content above or below the wilting coefficient.	1	......	+ 3.5	+ 8.9	− 2.0	+ 8.0	......	......	......	− 7.2	......	+2.2
	2	......	+12.3	+ 6.9	+ .8	+ 8.6	......	......	......	+ 2.1	......	+6.1
	3	......	+ 6.9	− 1.3	+ 2.9	+ 9.7	......	......	......	+ 5.5	......	+4.7
	4	......	+ 4.3	− 4.5	+ 7.3	......	......	......	......	+ 7.7	......	+3.7
Salt content	1	0.43	2.18	2.30	.25	1.36	1.85	1.36	.55	.18	2.18	1.26
	2	.82	2.08	1.64	.26	1.24	1.36	.91	.24	.76	1.85	1.11
	3	.98	1.64	1.36	.19	2.30	.88	.98	......	.76	......	1.13
	4	......	1.24	1.16	.44	......	.88	.98	......	......	......	.94

[1] All data in this table are stated in percentages of the dry weight of the soil. The moisture contents with a plus sign (+) represent moisture available for growth (above the wilting coefficient), while those with a minus sign (−) represent a corresponding deficit of available moisture (below the wilting coefficient).

Several of these samples—e. g., Nos. 76 and 97—were taken at places where Allenrolfea grew in company with Sarcobatus and where the salt content and moisture content of the soil were lower than in the typical Allenrolfea community. It is clear, nevertheless, that the presence of this plant is an almost invariable indicator that the soil (1) contains moisture available for growth, at least below the surface foot, throughout the summer; and (2) is excessively saline to a depth of at least 4 feet.

Salicornia Utahensis Community

Appearance and Botanical Composition.—*Salicornia utahensis*[1] (Pl. XLVIII, fig. 2) is a nearly leafless plant with fleshy, jointed stems. It resembles small plants of Allenrolfea, but is readily distinguished by the light blue-green color and by the fact that the branches are opposite, while in Allenrolfea they are alternate. It spreads by creeping rootstocks and forms pure colonies of greater or less size which sometimes cover the bottoms of depressions (see right end of Pl. XLIII, fig. 1), sometimes occupy hummocks elevated but a few inches above the general surface of the flats. In this case the appearance is much like the Allenrolfea hummocks (Pl. XLVIII, fig. 1), except that the latter are higher and the plants are larger and darker colored. This Salicornia is also found in association with Allenrolfea and with Distichlis.

Physical Conditions Indicated.—No determinations were made of the moisture equivalent and moisture content of the soil where this community occurs, but two borings carried to a depth of 30 inches and 12 inches, respectively, showed that abundant moisture was present throughout that depth, as would be expected from the slight elevation of the land above the water surface of the lake. The salt contents of different depths of the soil from the borings in question are given in Table XVII.

Table XVII.—*Salt content of soil in the Salicornia utahensis community.*

Depth of soil.	Salt content.	
	Sample No. 1.	Sample No. 2.
Inches.	*Per cent.*	*Per cent.*
0 to 6	2.20	>2.50
7 to 12	>2.50	....
0 to 12	....	2.25
13 to 18	>2.50	....
18 to 30	2.20	....

Salicornia Rubra Community

This small, shallow-rooted annual species of Salicornia is found most abundantly in pure communities along drainage channels in the salt flats. The patches of *Salicornia rubra* are very conspicuous late in the summer,

[1] This species was recently described from specimens collected by the writers in Tooele Valley by Mr. Ivar Tidestrom. (A new Salicornia. Proc. Biol. Soc. Wash., v. 26, p. 13, 1913.)

owing to the bright-red color then assumed by the plants. Scattered individuals of this species were also observed far out on the otherwise bare salt flats.

CORRELATIONS BETWEEN THE TYPES OF VEGETATION AND THE CHARACTER AND PRODUCTIVITY OF THE LAND

CORRELATIONS WITH PHYSICAL CONDITIONS

The natural vegetation of Tooele Valley consists of a few easily recognizable plant communities, the distribution of which is largely determined by the moisture relations and the salt content of the soil. The areas occupied by each community are rather sharply delimited, although

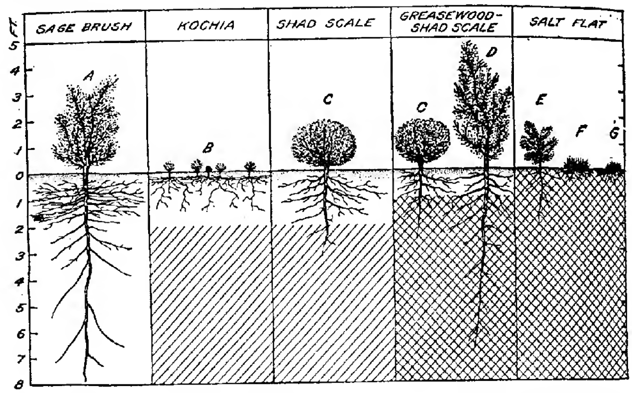


FIG. 13.—Diagram showing the characteristic root development of the dominant species of each of the principal types of vegetation of Tooele Valley, and indicating the average conditions of soil moisture and salinity of the corresponding types of land. The double hatching indicates soil containing an excessive quantity of salt (more than 0.5 per cent) and containing moisture available for growth (above the wilting coefficient) during the summer. The single hatching indicates soil containing more than 0.5 per cent of salts and no moisture available for growth during the summer. No hatching indicates soil containing less than 0.5 per cent of salts and no moisture available for growth during the summer. A, *Artemisia tridentata;* B, *Kochia vestita;* C, *Atriplex confertifolia;* D, *Sarcobatus vermiculatus;* E, *Allenrolfea occidentalis;* F, *Salicornia utahensis;* G, *Distichlis spicata.*

along their boundaries, where the soils are of an intermediate character, the vegetation is more or less mixed. Where, as a result of the removal of the original vegetation by fire or by the plow, secondary plant communities have developed, the correlations between the vegetation and the physical properties of the underlying soils are not always well marked. But with these exceptions, which have been sufficiently discussed on preceding pages, all important variations in the character of the soil are clearly expressed in the appearance and botanical composition of the plant covering. In other words, the principal types of vegetation, where typically developed, are reliable indicators of the physical conditions of the environment. These correlations are stated in Table XVIII, which follows, and are graphically represented in figure 13.

TABLE XVIII.—*Principal types of vegetation of Tooele Valley in relation to average soil moisture and salinity conditions.*[1]

Plant community.	Moisture and salinity conditions.		
	Source of moisture.	Surface foot of soil.	Soil below surface foot.
Sagebrush	Direct precipitation	Nonsaline, usually dry in summer.	Nonsaline, usually dry in late summer.
Sand-hill mixed.	do	do	Nonsaline, usually (?) moist in summer.
Shadscale	do	do	Saline, usually dry in late summer.
Kochia	do	do	Saline, usually dry in late summer.
Greasewood-shadscale	Direct precipitation and high water table.	Saline or nonsaline, usually dry in summer.	Saline, moist.
Grass flat	Direct precipitation, high water table, springs and irrigation.	Moderately saline, moist.	Moderately saline, moist.
Salt flat	Direct precipitation and high water table.	Saline, moist	Saline, moist.

[1] The term "dry" as here applied to the soil indicates that its water content is below the wilting coefficient. The term "moist" implies that moisture available for plant growth (above the wilting coefficient) is present.

The average conditions as respects moisture and salinity of the soil which characterize the land occupied by each of the more important types of vegetation are stated in Table XIX. The data for the different samples upon which these averages are based are given in full under the respective associations (Tables IV, IX, X, XII, XV, and XVI). Only typical areas of each plant community have been taken into account in computing the averages.

TABLE XIX.—*Moisture conditions and salt content of the soil in typical areas occupied by the principal plant communities.*[1]

Soil depth (feet).	Plant community.					
	Sagebrush (*Artemisia tridentata*).	Kochia (*Kochia vestita*).	Shadscale (*Atriplex confertifolia*).	Greasewood-shadscale (Sarcobatus and Atriplex).	Grass flat. Salt grass (*Distichlis spicata*).	Salt flat. *Allenrolfea occidentalis*.
MOISTURE EQUIVALENT.						
1	14.2	25.8	22.9	24.1	34.1	26.7
2	15.6	27.0	31.0	26.6	31.8	23.4
3	16.5	33.5	34.5	26.1	33.3	21.8
4	15.8	31.9	30.6	26.9	49.1	30.4

[1] All data are given as percentages of the dry weight of the soil.

TABLE XIX.—*Moisture conditions and salt content of the soil in typical areas occupied by the principal plant communities*—Continued.

Soil depth (feet).	Plant community.					
	Sagebrush (*Artemisia tridentata*).	Kochia (*Kochia vestita*).	Shadscale (*Atriplex confertifolia*).	Greasewood-shadscale (Sarcobatus and Atriplex).	Grass flat. Salt grass (*Distichlis spicata*).	Salt flat. *Allenrolfea occidentalis*.
WILTING COEFFICIENT.						
1	7.7	14.0	12.4	13.1	18.5	14.5
2	8.5	14.7	16.8	14.4	17.3	12.7
3	8.9	18.2	18.7	14.2	18.1	11.8
4	8.6	17.3	16.6	14.6	26.7	16.5
MOISTURE CONTENT ABOVE OR BELOW WILTING COEFFICIENT.						
1	−2.5	−5.4	−5.6	−2.4	+9.6	+2.2
2	−.6	−1.8	−5.2	+3.6	+13.5	+6.1
3	−1.3	−2.5	−5.0	+5.7	+11.4	+4.7
4	+1.0	−2.4	−5.5	+5.3	+13.8	+3.7
Average	−.8	−3.0	−5.3	+3.0	+12.1	+4.2
SALT CONTENT.						
1	0.03	0.12	0.07	0.34	1.07	1.26
2	.03	.55	.32	.72	.97	1.11
3	.05	1.02	.78	1.03	.76	1.13
4	.07	1.11	.93	1.15	.64	.94
Average	.04	.70	.52	.81	.86	1.11

CORRELATIONS WITH CROP PRODUCTION.

The capabilities of the principal types of land in Tooele Valley for crop production with or without irrigation are summarized in Table XX.

TABLE XX.—*Crop-producing capabilities of the land as indicated by a normal growth of the different types of vegetation.*

Type of vegetation.	Is land capable of crop production? Without irrigation.	With irrigation.
Sagebrush	Yes	Yes.
Kochia	Precariously in years of rainfall above the normal.	Yes; if alkali can be removed.
Shadscale	Precariously; conditions rather more favorable than on Kochia land.	Yes; after alkali is removed.
Greasewood-shadscale	No	Yes; after alkali is removed.
Grass flats	Probably not	Possibly, with drainage.
Salt flats	No	No.

SAGEBRUSH LAND.—This is the only type in Tooele Valley which is well adapted to dry farming. Practically all of the area devoted to wheat in this valley was doubtless originally occupied by the sagebrush association. Most of this area is situated on the eastern side of the valley, where the rainfall is heavier than on the western side. But the presence of sagebrush does not necessarily indicate good conditions for dry farming. Where the stand is thin and the plants are small and unthrifty, the depth of good soil is too slight for profitable crop production without irrigation. Sagebrush vegetation of this character indicates the presence of gravelly hardpan, or else of an excessive quantity of alkali salts, at a depth of only 2 or 3 feet.

A good growth of sagebrush also indicates the best land for farming under irrigation. Because of the low water table and the absence of alkali salts, such land is not likely to require artificial drainage.

KOCHIA LAND.—Dry farming is sometimes attempted on Kochia land, rye being the crop which is usually grown. The yields obtained are very small, at least in years of only normal rainfall, the depth of good soil being narrowly limited by the strongly saline subsoil. Whether Kochia land is suitable for irrigation farming is somewhat doubtful, since the rather impervious character of the soil might make it difficult to leach the salts to a sufficient depth to insure profitable crop production.

SHADSCALE LAND.—Dry farming is precarious on this type of land. On the other hand, it seems probable that most of the shadscale land in Tooele Valley would produce crops under irrigation, if water for this purpose were available, since as compared with Kochia land the soil is more permeable and there is greater likelihood that the salts could be leached out of the subsoil.

GREASEWOOD-SHADSCALE LAND.—One or two attempts at crop production without irrigation on this type of land were observed, but the results seemed to be no better than on Kochia and on shadscale land. The reason doubtless is that while the moisture conditions are more favorable than on the latter types the salt content of the soil at only a slight depth is too high to permit crop plants to make a satisfactory root development.

On the other hand, greasewood-shadscale land when irrigated and reclaimed produces good crops of alfalfa, grain, and even of orchard fruits. Artificial drainage, however, would probably be required in case an extensive area of this type of land were under irrigation, the water table being already high and the subsoil strongly saline.

GRASS-FLAT LAND.—This type of land affords pasturage to horses and cattle and is therefore by no means negligible as one of the agricultural resources of the valley. Drainage would probably be necessary in order to fit it for crop production.

SALT-FLAT LAND.—Most of the area occupied by this type of vegetation is too wet and too saline for crop production and offers little prospect of successful reclamation.

SUMMARY

In Tooele Valley the different types of native vegetation indicate the conditions of soil moisture and salinity of the land on which they are found and thus afford a basis for estimating its capabilities for crop production. These correlations are stated in Table XVIII (p. 413), Table XIX (p. 413), and Table XX (p. 414).

The sagebrush (*Artemisia tridentata*) association covers the land nearest the mountains where the soil is of rather light texture, permeable, rather low in moisture-holding capacity, and free from an excess of alkali salts and where under natural conditions the moisture available for growth is usually exhausted early in summer. A good stand and growth of sagebrush indicates land that is well adapted to both dry-farming and irrigation farming; but where the stand is thin and the growth poor the depth of good soil is usually too small for profitable crop production, at least without irrigation.

The Kochia (*Kochia vestita*) association covers areas lying just below the sagebrush belt and also occupies islands in the midst of the latter vegetation. The soil, which is remarkably homogeneous, differs from that of sagebrush land in its finer texture, relative impermeability, higher moisture-holding capacity, and the high salt content of the subsoil. The first foot of soil is usually free from an injurious quantity of alkali salts. Moisture available for growth is usually wanting during the summer to a depth of at least 4 feet and probably to a much greater depth. Dry farming is precarious on such land, owing to the small depth of soil free from alkali. Even under irrigation the relatively impervious nature of the soil might hinder washing out the salts to a depth which would permit profitable crop production.

The shadscale (*Atriplex confertifolia*) association occupies the land next below the Kochia belt. The soil is similar, in the main, to that where Kochia occurs, but frequently contains much gravel, is usually even drier during the summer months, and has on the average a somewhat smaller salt content. Dry farming is nearly as precarious on shadscale land as on Kochia land, but where water is available for irrigation the salts could probably be leached to a greater depth than on Kochia land, the soil being more permeable.

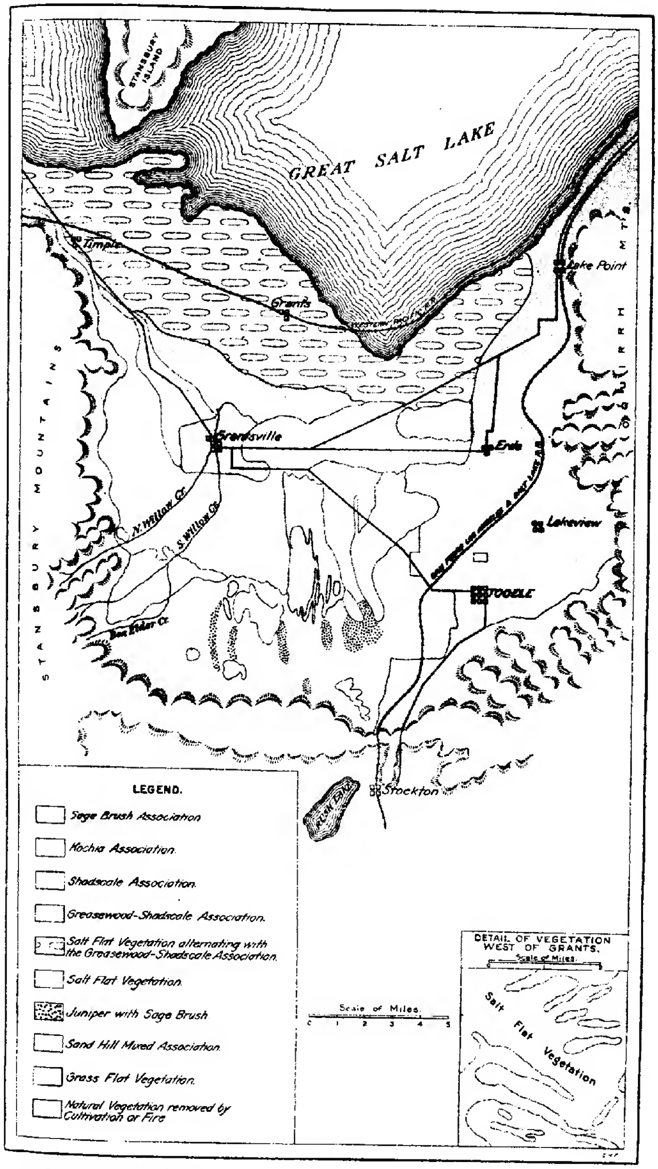
The greasewood-shadscale (*Sarcobatus vermiculatus* and *Atriplex confertifolia*) association occupies a belt lying between the pure shadscale vegetation and the salt flats and also crowns the ridges and knolls which intersect the latter. The soil differs from that of any of the foregoing associations in usually containing, during the summer, moisture available for growth at all depths below the surface foot. It is also strongly saline below the depth of 1 foot, and even the surface foot often contains a considerable quantity of salts. Land of this type is not suitable for dry farming, but can be made to produce good crops under irrigation, especially when drainage is provided.

The presence of the grass-flat (Sporobolus, Distichlis, Chrysothamnus) vegetation indicates a soil which has a high moisture capacity, is more or less saline, and is moist to the surface during a great part of the year. Such land produces a coarse natural pasturage, but is not suitable for crop production unless it is drained.

The salt-flat (Allenrolfea, Salicornia) vegetation occupies land which is extremely saline and is wet to the surface during a great part of the year. This type of land is not adapted to crop production.

The correlations above outlined are yet known to apply only in Tooele Valley. Further investigation is needed in order to establish their applicability in the classification of agricultural land in other parts of the Great Basin.

PLATE XLII. Sketch map showing the distribution and relative areas of the different types of vegetation in Tooele Valley, with detail showing depressions covered with salt-flat vegetation alternating with ridges bearing greasewood-shadscale vegetation.



THE NORRIS PETERS CO., WASHINGTON, D. C.

PLATE XLIII. Fig. 1.—Salt-flat vegetation bordering Great Salt Lake with a greasewood-shadscale ridge in the foreground, a pure stand of *Salicornia utahensis* at the right and hummocks covered with *Allenrolfea occidentalis* in the background.

Fig. 2.—Sagebrush association (the darker areas) and islands of Kochia vegetation (the lighter areas) in the upper part of Tooele Valley. The sagebrush is encroaching upon the Kochia (at left).


1


2

PLATE XLIV. Sagebrush (*Artemisia tridentata*). Fig. 1.—A good stand and growth, showing the typical appearance of this association where the conditions are relatively favorable. *Juniperus utahensis* in the background.

Fig. 2.—Plants showing the root habit; photographed at the edge of a deep "arroyo" where the soil had recently caved in. The extensive development of the lateral roots in the upper soil and the penetration of the taproot to a depth of about 11 feet is illustrated.

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PLATE XLV. Fig. 1.—Sagebrush land which has recently been burned over, showing scattered, dead plants of *Artemisia tridentata* (no living ones), a dense growth of the annual grass *Bromus tectorum*, and scattered plants (dark colored in the picture) of *Gutierrezia sarothrae*.

Fig. 2.—An advanced stage in succession on sagebrush land which has been under cultivation, with numerous young plants of *Artemisia tridentata* and a dense herbaceous covering of *Bromus tectorum* and alfilaria (*Erodium cicutarium*).

Fig. 3.—Sagebrush reestablished on land which has been in cultivation (right) and the original, undisturbed sagebrush vegetation (left). The Stockton embankment in the background.

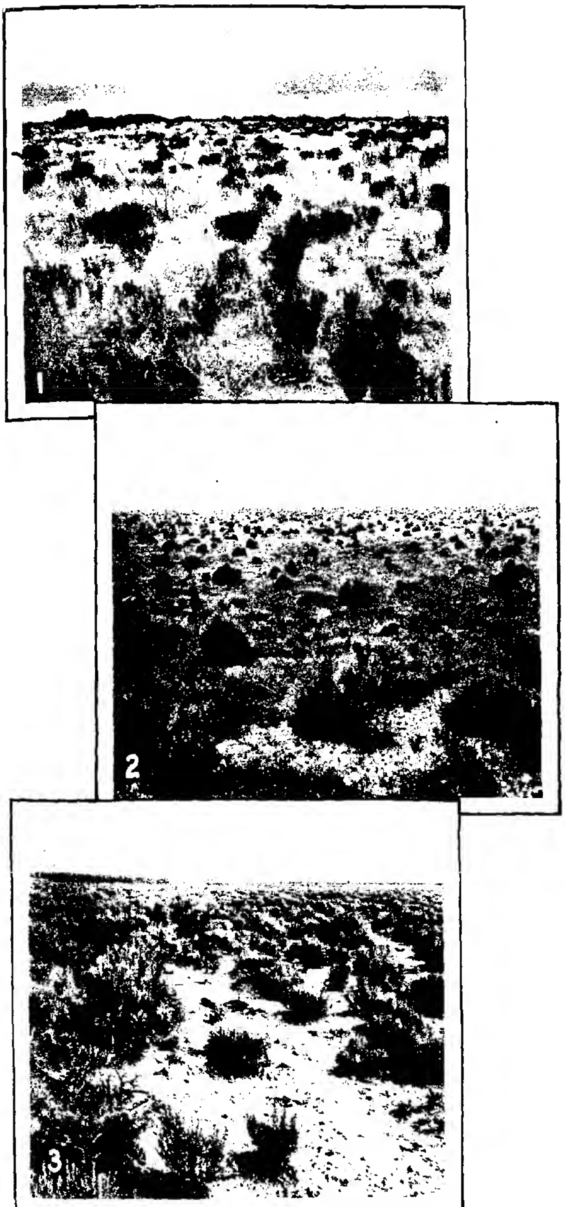


PLATE XLVI. Fig. 1.—Line of contact between the sagebrush association (right hand) and the Kochia association (left hand), showing the characteristically sharp demarcation of the two types. Soil samples collected at each side of this line, at points only 20 feet apart, showed that in the Kochia land there was ten times as much salt in the first foot and seventy-five times as much in the second foot as in the sagebrush land.

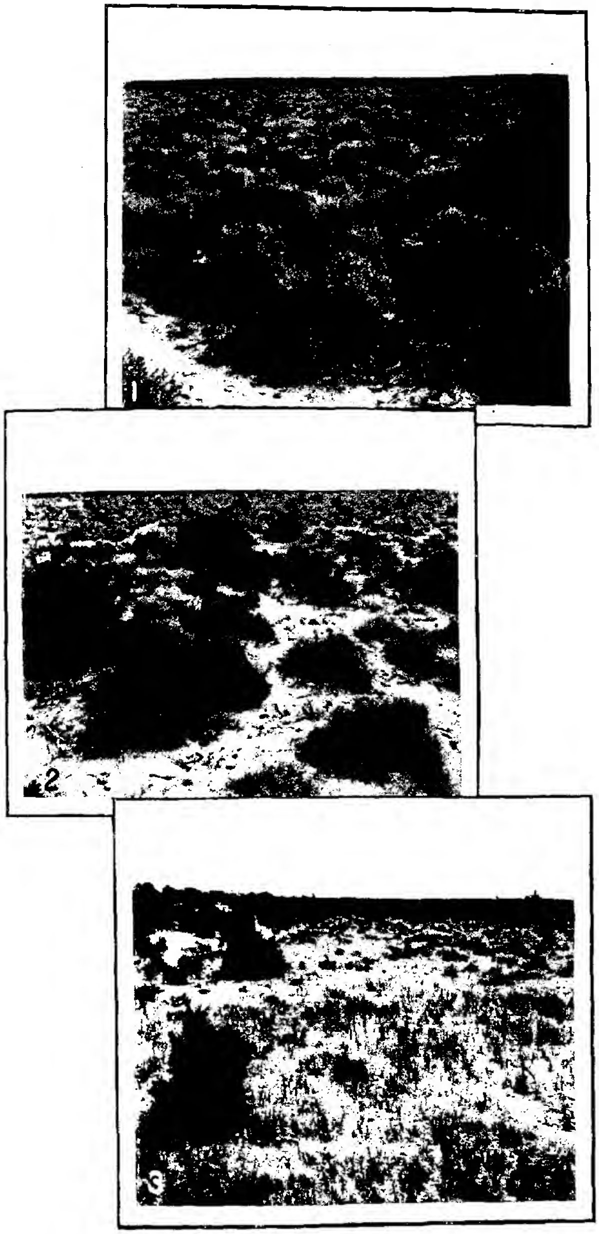
Fig. 2.—A typical view of the Kochia association, with plants rather far apart, and very uniform in size and appearance. This land has been pastured, which has resulted in the removal of practically all grasses and other species which occur in this association when protected from grazing animals.

Fig. 3.—Plants of *Kochia vestita*, 4 or 5 inches high, and the grass *Poa sandbergii*, which is usually associated with the Kochia in land that is not grazed.

PLATE XLVII. Fig. 1.—Typical shadscale vegetation, consisting of a nearly pure stand of *Atriplex confertifolia*, showing much dead wood, as is usually the case, but the stand is denser than in much of the area occupied by this association.

Fig. 2.—Transition area between the shadscale and the greasewood-shadscale types of vegetation. Scattered (larger and darker colored) plants of greasewood (*Sarcobatus vermiculatus*) in an area occupied chiefly by shadscale.

Fig. 3.—Salt grass (*Distichlis spicata*) covering the whole of the depression to the right with the exception of a colony of Allenrolfea in the middle distance. The higher land to the left is occupied by greasewood (very dark in the illustration) and shadscale.



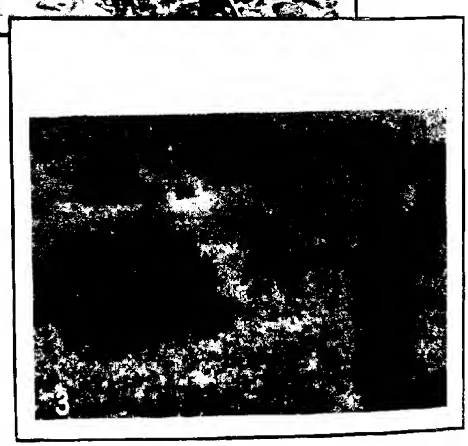


PLATE XLVIII. Fig. 1.—Salt-flat vegetation, Allenrolfea community. The ground between the hummocks is covered with a white crust of salts, mostly sodium chlorid.

Fig. 2.—Salt-flat vegetation, showing plants of *Salicornia utahensis*.

Fig. 3.—Grass-flat vegetation, Sporobolus-Chrysothamnus community, showing a species of rabbit brush, associated with tussock grass.

CITROPSIS, A NEW TROPICAL AFRICAN GENUS ALLIED TO CITRUS

By WALTER T. SWINGLE, *Physiologist in Charge*, and MAUDE KELLERMAN, *Botanical Assistant, Crop Physiology and Breeding Investigations, Bureau of Plant Industry*

INTRODUCTION

Missionaries and pioneer explorers of equatorial Africa long ago reported the finding of wild oranges and wild lemons. If the fruits were green, they resembled small limes and lemons; if ripe, their sweet and agreeable flavor caused them to be classed as oranges.

These fruits are from 2 to 3 cm. in diameter and are borne, two to five or more in a cluster, in the axils of the leaves. Because of this pecul-

FIG. 1.—*Citropsis Schweinfurthii:* A branch showing 3-foliate and 5-foliate leaves, leaflike petioles, and rachis segments; also paired and single spines in the axils of the leaves. From a plant in greenhouse of the Department of Agriculture grown from seed from Budongo Forest, Uganda, Africa. (C. P. B. No. 2902.) One-fourth natural size.

iarity they may be called African cherry oranges. The leaves are odd-pinnate, usually with five leaflets, but often trifoliate. The petioles and the segments of the rachis are so broadly winged that in some species they look not unlike leaflets. (See fig. 1.)

As early as 1870 Schweinfurth, the veteran African explorer, had collected leafy twigs of one of these plants, but no flowers or fruits, in the

"Galleriewaldungen" at Uando, near the divide between the Congo and the Bahr-el Ghazal drainage basins. In 1880 Soyaux collected specimens of another species in Gabun (French Congo). In 1882 Pogge collected material at Lulua in Congo proper, and in 1890 Preuss found still another very distinct species on the shores of Elephant Lake in Kamerun. Early in 1895 Prof. Adolph Engler described four new species of Limonia to include these plants.[1] In November of the same year he segregated these African species of Limonia as a new section, Citropsis, in contradistinction to the true Limonias of the Asiatic mainland.[2]

Since then several additional species have been described from tropical Africa, and it is now clear that these plants occur not uncommonly throughout central Africa from the Ivory Coast in the west to Uganda in the east.

In connection with a study of the plants related to Citrus, these African species of the Citropsis section of Limonia have been carefully examined. The material of this section in the principal European collections of African plants has been studied and a number of representative specimens secured, through the generosity of M. Émile de Wildeman, of Brussels, and M. Auguste Chevalier, of Paris. Mr. B. T. Dawe, formerly Forest Administrator of Uganda, who had discovered a new species (*Limonia ugandensis* Baker) in the forests bordering the north shore of Victoria Nyanza, sent to the Department of Agriculture at Washington in 1910 both good herbarium specimens and viable seed.

As a result of these investigations, which have been in progress some three years, it is now clear that these plants have been wrongly placed in the Asiatic genus Limonia. Instead of constituting a section of this genus, they are in reality only remotely related to the type species from Asia (*Limonia acidissima* L.) and are, on the other hand, closely and clearly related to Citrus.

The *Limonia acidissima* (*Hesperethusa crenulata* (Roxb.) Roem.) of India has small, globose fruits only 12 mm. or less in diameter, becoming a purple-black, bitterish berry when ripe. Each of the four cells of the fruit contains a single seed surrounded with mucilage. There are no pulp vesicles. The fruits are, thus, of an entirely different structure from Citropsis and are like those of many Asiatic genera, such as Lavanga, Triphasia, Severinia, etc., which constitute a natural group.

Besides the very important differences in the structure of the fruit, *Limonia acidissima* differs from Citropsis in having free-spreading stamens with slender filaments. None of the other Asiatic species usually referred to Limonia are any more closely related to Citropsis than is *Limonia acidissima*.

[1] Engler, A. Diagnosen neuer Arten. *In* Notizbl. K. Bot. Gartens u. Mus. Berlin. Bd. 1, No. 1, p. 28–29. Jan. 2, 1895.

[2] Engler, A. Rutaceæ. *In* Engler, Adolf, and Prantl. Natürlichen Pflanzenfamilien. T. 3, Abt. 4, p. 189–190, fig. 109, E–H. Leipzig, 1895.

That the African species of Limonia constituting the section Citropsis are related to Citrus rather than to the Asiatic species of Limonia is a conclusion, based at first on a study of herbarium and living material, that has since been confirmed in gratifying manner by the results of experiments in grafting, which show that the African species belonging to the section Citropsis can be budded easily and grow well on all the commonly cultivated species of Citrus.

TECHNICAL DESCRIPTION OF CITROPSIS

It seems necessary to establish a new genus to include these African cherry oranges. This is best done by raising to generic rank the section Citropsis of Engler.[1]

Citropsis (Engler) Swing. and M. K.

The genus Citropsis resembles Citrus in the general structure and appearance of the flowers and fruit, as well as in the texture, venation, and general type of the leaves. It differs from Citrus in having 4- or rarely 5- merous ovaries, with only a single ovule in each cell; fruits with sessile pulp vesicles which are broad at the bases where they are embedded in the endocarp; the stamens only twice as numerous as the petals; large compound leaves; and spines usually occurring in pairs. The leaves are odd pinnate, 5- or rarely 7-foliate, trifoliate, or sometimes unifoliate, subcoriaceous, pellucid punctate. The spines are paired or single in the axils of the leaves. The flowers occur in few- or many-flowered axillary clusters and are perfect, 4- or rarely 5-merous. The stamens are twice as numerous as the petals, free but flattened, and arranged to form a staminal tube surrounding the pistil much as in Citrus. The disk subtends and is slightly larger than the base of the ovary. The ovaries are 4- rarely 5-celled with one ovule in each cell. The style is long and deciduous; the stigma is large, subglobose, more or less 4- rarely 5-lobed. The fruit is globular or subglobular, small (2 to 3 cm. in diameter), with a fleshy skin like that of a lime, dotted with oil glands. The pulp is vesicular, either sweet and edible or waxy. The pulp vesicles are not stalked as in Citrus, but are broad at the base where they are embedded in the endocarpic lining of the cells and taper gradually toward the pointed tips. In some species they are full of juice, in some they contain a waxy substance, and in some they dry up as the fruit develops. The seeds are large, 10 by 6 by 4 mm., with a hard, parchmentlike testa having a foramen at the tip. The cotyledons remain hypogeous in germination. The first two foliage leaves are opposite, as in Citrus.[2] (See fig. 2.)

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[1] **Citropsis**, gen. nov. (Limonia, § Citropsis, Engler).—Genus *Citro* affinis, foliis pinnatis, staminibus paucioribus (staminum numero petalorum duplo nunquam quadruplo), ovariis 4- rarius 5- locularis, loculis monospermis.

Folia imparipinnata, trifoliata vel rarius unifoliata, subcoriacea, pellucido-punctata. Spinae in axillis foliorum geminae vel singulae. Paniculae axillares, pauciflores. Flores hermaphroditi, 4- vel rarius 5-meri. Stamina 8 vel 10 (numero petalorum duplo). Discus ovarii basim subtendens. Ovarium 4- vel rarius 5- locularis, stylus longus, deciduus, stigma plus minusve quadrilobum, ovulo in loculo singulo. Fructus globosus vel subglobosus, cortice ut in *Citro* carnoso, glandulis oleiferis instructo, pulpa vesiculari, dulci et eduli, vel cerea, vesiculis fusiformibus, ad basin in endocarpio immersis. Semina magna, testa dura, pergamena, foraminea. Cotyledones in germinatione hypogaeae.

Arbor parva vel arbuscula, spinosa.

Species typica, *Limonia Preussii* Engler.

[2] In *Citropsis Schweinfurthii* the first two postcotyledonary leaves are opposite, broadly oval, and short stalked; the next two or three leaves are simple, with short petioles; then follow unifoliate leaves with winged, longer petioles; then trifoliate leaves; and finally pinnately 5-foliate leaves. (See fig. 2.)

Shrubs or small trees; native to tropical Africa.

The type species is *Limonia Preussii* Engler, from Kamerun.

Citropsis is related to Citrus on the one hand and to Atalantia on the other. It differs from both in its compound leaves and broad-based pulp vesicles partly embedded in the endocarp and from Atalantia in

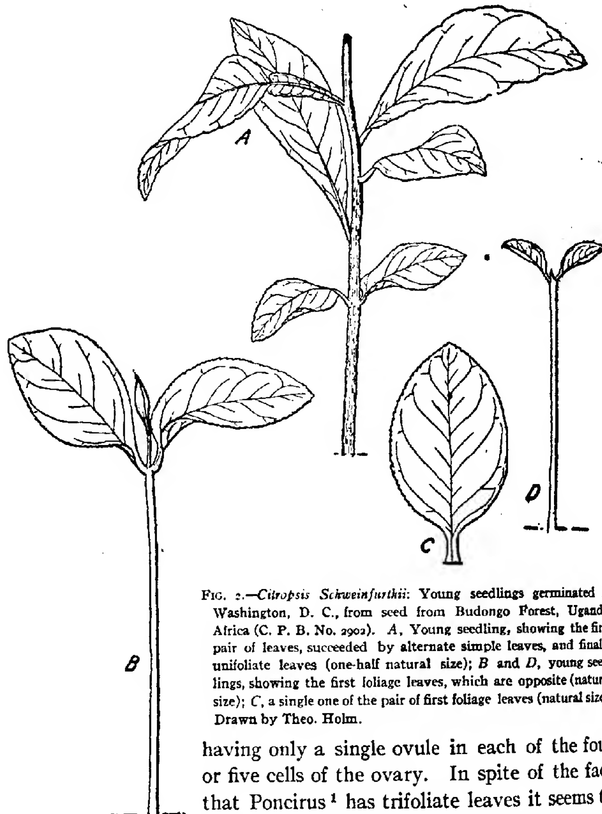

FIG. 2.—*Citropsis Schweinfurthii*: Young seedlings germinated in Washington, D. C., from seed from Budongo Forest, Uganda, Africa (C. P. B. No. 2902). *A*, Young seedling, showing the first pair of leaves, succeeded by alternate simple leaves, and finally unifoliate leaves (one-half natural size); *B* and *D*, young seedlings, showing the first foliage leaves, which are opposite (natural size); *C*, a single one of the pair of first foliage leaves (natural size). Drawn by Theo. Holm.

having only a single ovule in each of the four or five cells of the ovary. In spite of the fact that Poncirus[1] has trifoliate leaves it seems to be less closely related to Citropsis than is Citrus. Poncirus differs from both Citrus and Citropsis in its deciduous leaves, sessile solitary flowers, clawed petals, spreading stamens, stalked pulp vesicles with external, branched, secreting hairs, and in having in germination the first postcotyledonary leaves in the form of alternate cataphylls.

[1] Poncirus Raf. includes *Citrus trifoliata* L., the type species, and as yet the only one known. *See* Swingle, Walter T. Poncirus (and Citrus). *In* Sargent, C. S. Plantæ Wilsonianæ. pt. 5. Cambridge, 1914.

CHARACTERS WHICH DISTINGUISH SPECIES OF CITROPSIS

The principal diagnostic characters of the species of Citropsis are found in the flowers, leaves, and fruits. The size, shape, and proportions of the pistil and in particular of the style are of great importance. The smoothness or hairiness of the filaments and the shape of the ovary are also important characters, as is the length of the pedicel and peduncle in relation to the length of the pistil. The shape, size, and proportions of the leaflets, segments of the rachis, and petioles are not only obvious but necessary characters for use in distinguishing the species. Finally, the nature of the fruit, whether dry or pulpy, and if pulpy, whether juicy and sweet, or waxy, is useful in distinguishing the species. Owing to the number of species of Citropsis and the variability due to their wide range, it is usually necessary to have at least good flowers and leaves to be able to determine the species with any certitude, and in some cases fruits also are necessary.

Inasmuch as none of the original descriptions of the African species of Limonia now referred to Citropsis included both flowers and mature fruits, it is obvious that it is a matter of much difficulty to determine the affinities of some of these species based on imperfect material.

Citropsis Preussii (Engler), n. comb.

Limonia Preussii Engler, 1895, *in* Notizbl. K. Bot. Gartens u. Mus. Berlin, Bd. 1, p. 28.
Illus., Engler, 1895, *in* Engl. and Prantl, Pflanzenfam., T. 3, Abt. 4, p. 189, fig. 109, E–H.

The following specimens[1] have been consulted: **Kamerun.**—Preuss (No. 548), September 19, 1890, Barombi Station on Elephanten See (Dahlem Herbarium[2]; Kew Herbarium). Standt (No. 747), November 29, 1896, Johann Albrechtshöhe (Dahlem Herbarium, fragment in National Herbarium, Washington, D. C.; British Museum Herbarium). Büsgen (No. 37), November 18, 1905, Johann Albrechtshöhe (Dahlem Herbarium). Ledermann (No. 1455), December 1, 1908, Bare (Dahlem Herbarium; fragment in National Herbarium, Washington, D. C.).[3]

The type of the genus, *Citropsis Preussii*, was first collected by Preuss at Barombi Station on the south shore of Elephanten See in Kamerun on September 19, 1890. Of his original collection (No. 548) three specimens, all showing good flowers, have been studied by the writers. (See fig. 3.) Two of these are preserved in the herbarium at Dahlem, near Berlin. The third was sent to Kew Gardens (April, 1894) before the species was published and evidently was not used by Prof. Engler in drawing up the original description, as the species is described as having trifoliate leaves, while those of the Kew specimen are 5-foliate.

Besides this original material there are three excellent sheets in the Dahlem Herbarium and one at South Kensington of material collected by Standt (No. 747) on November 29, 1896, at Johann Albrechtshöhe,

[1] All of the specimens cited from European herbaria were photographed by one of the writers in 1911–12, and prints enlarged to natural size have been filed in the National Herbarium at Washington, D. C.

[2] The sheet to which the original label is attached is the type specimen.

[3] Ledermann's specimens have been designated "*Limonia Preussii* Engl., var. *micrantha* Engl.," but it is probable that the very small flowers are due to a diseased condition of the plant and do not constitute a true varietal difference.

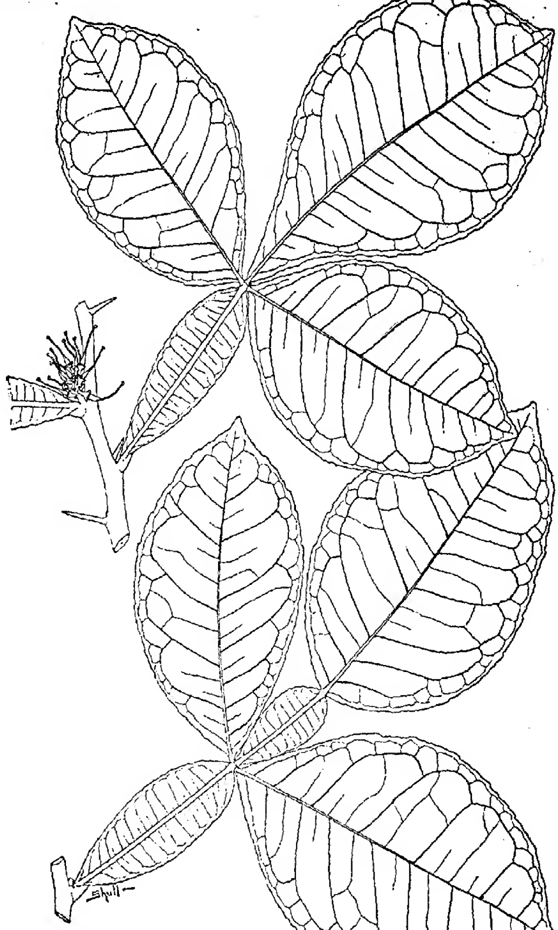

FIG. 3.—*Citropsis Preussii:* Flowers after petals and stamens have fallen; leaves, one trifoliate and one having the terminal leaflet borne on a winged segment of the rachis. From paratype, Standt No. 548, in Dahlem Herbarium. One-half natural size.

near the original type locality on Elephanten See. These specimens show flowers and young fruits. Finally, there is one sheet in the Dahlem Herbarium, collected by Büsgen (No. 37) on November 18, 1905, also at Johann Albrechtshöhe near Elephanten See. This specimen shows young fruits.

All of this material comes from the same general locality, Johann Albrechtshöhe being only 3 or 4 km. distant from Barombi Station. All eight of these specimens show a great resemblance and undoubtedly belong to a single species. Unfortunately all were collected in the autumn and show only flowers and very young fruits.

A number of other specimens have been referred to *Citropsis Preussii* in the Dahlem Herbarium, but some of them certainly do not belong here, and for the present the only material certainly referable to this species is that collected in the immediate vicinity of Elephanten See in Kamerun.

The excellent specimens with flowers and young fruit and numerous leaves permit a very good idea to be gained of this species.

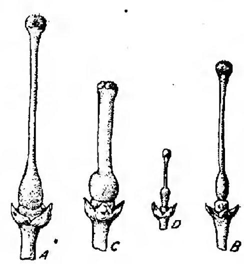

FIG. 4.—Pistils of four species of Citropsis. *A*, *Citropsis Preussii* (Standt No. 747); *B*, *Citropsis mirabilis* (Chevalier No. 21609); *C*, *Citropsis Schweinfurthii* (C. P. B. 2902); and *D*, *Citropsis gabonensis* (Klaine No. 2260). Twice natural size.

The leaves are 3- to 5-foliate, with broadly winged petiole and rachis. (See fig. 3.) The leaflets are very large, 100 to 160 by 45 to 115 mm., broadly oval or oblong, abruptly narrowed above into a short obtuse tip, and broadly cuneate at the base, with very short petiolules. Petioles usually 69 to 80 by 25 to 35 mm., elongate, elliptical, rather acute at tip and base, but sometimes shorter and broader or even obcordate 30 to 40 by 25 mm. The segments of the rachis are elongate elliptical, 50 to 70 by 15 to 25 mm. Spines usually single, 16 to 28 mm. long, rarely wanting. Flowers 15 to 18 mm. long in the bud, 20 to 25 mm. in diameter when open, in dense many-flowered clusters borne in the axils of the leaves, very short pediceled (3 to 5 mm.), usually 4-merous, ovaries 12 to 15 mm. long, with a long, slender style broadening at the base and merging gradually into the ovary. Only young fruits are known as yet. These are short-stalked or nearly sessile, slightly apiculate.

Citropsis Preussii is readily distinguished from its congeners by the broadly oval or oblong leaflets, and by the short-stalked flowers with very long styles broadened at the base and not sharply delimited from the tip of the pointed ovaries. *Citropsis mirabilis* resembles this species in the shape of the leaves, winged petioles, and rachis, but differs in the longer stalked flowers, which have a shorter more slender style which is not broadened at the base and consequently is more sharply delimited from the tip of the more rounded ovary. (See fig. 4.)

collected by J. Milbraed in 1908, which seem to be referable to *Citropsis Schweinfurthii*. One specimen (No. 2394) is from Fort Beni, in extreme western Uganda, on the Semliki River, about half way between Albert Nyanza and Albert Edward Nyanza. This specimen consists of a single twig with 5-foliate leaves, single spines, and two young fruits. The other (No. 2280) is from Kikufu, near Irumu, in the Ituri River valley, only a few kilometers south of the ferry where Stuhlmann crossed the Ituri and collected his No. 2641. This second specimen of Milbraed consists of two twigs with mostly 5-foliate leaves, but one of them has a trifoliate leaf almost exactly like those of Schweinfurth's original specimen from Uando.

Limonia Poggei Engler, which the writers have referred doubtfully to *Citropsis Schweinfurthii*, was based on a single specimen collected by Pogge (No. 668) June 1, 1882, at Lulua, latitude 6° S., on the Lulua River, an affluent of the Kasai River. The type specimen preserved in the Dahlem Herbarium shows a single twig with 11 or 12 internodes, but with only one 5-foliate leaf remaining attached. There is also one loose leaf and a single fruit. Pogge's original label notes that the fruit is yellow. An examination of the fruit preserved with the type specimen at Dahlem shows it to possess distinct pulp vesicles. There is nothing in the specimen or in the description to distinguish it from *Citropsis Schweinfurthii*, and as it occurs at a considerable altitude, 660 meters, and only 500 km. west from the nearest of the great African lakes, while Uando, the type locality, was some 250 km. west, its geographic range is not such as to render its inclusion in the species improbable.

It is interesting to note that all the reported localities of *Citropsis Schweinfurthii* are above 660 meters altitude, the highest reported being 1,550 meters at Toro, Mpanga Forest, Uganda.

There is, however, a specimen in the herbarium of the Muséum d'Histoire Naturelle at Paris, collected by Thollon (No. 1049) in June, 1888, in French Congo on the Niari River between Bounanza and Komba, that can scarcely be distinguished by its leaf characters from *Citropsis Schweinfurthii*. Bounanza is only 250 km. from the Atlantic Ocean and at an altitude of only 130 meters. Thollon states on his original label that this plant occurs in all the woods from Komba to Bounanza. If this material proves to be *Citropsis Schweinfurthii*, it will give this species the greatest range both in distance and in altitude of any yet known in the genus Citropsis.

There is a specimen[1] in the herbarium of the botanic garden at Brussels, collected by Messrs. Ém. and M. Laurent below Ibaka, on the Sankuru River, Congo, on November 24, 1903, and also a specimen in the National Herbarium at Washington, D. C., collected by Messrs. Laurent below Bolombo, on the Sankuru River, on January 2, 1904.

[1] This specimen seems to have been referred to *Limonia Demeusei* by M. Émile de Wildeman. *See his* Mission Émil Laurent (1903-4). v. 1, p. 238. Brussels, 1905-1907.

Both of these specimens, as well as one in the herbarium at Brussels, collected in Congo by Messrs. Laurent in 1903–4, but without exact locality or date, have trifoliate leaves, long, slender leaflets, with the terminal one disproportionately long, being 110 to 165 by 30 to 45, while the adjacent lateral leaflets are 65 to 90 by 25 to 45; thus the terminal leaflet is from two-fifths to one-third longer than the lateral. The only species to which these specimens can be referred at present is *Citropsis Schweinfurthii*, but in the absence of flowers and fruits and because of the rather unusual appearance of the leaves such reference must be merely provisional.

Citropsis Schweinfurthii is a spiny shrub or small tree with 3- to 5-foliate leaves. The flowers are borne in clusters of 4 to 10 in the axils of the leaves. (See fig. 6.) They are 4- or rarely 5-parted with strap-shaped petals, a short, thick style, 6 to 9 mm. long, scarcely narrower than the stigma but rather sharply set off from the rounded tip of the ovary, and broad flattened filaments with a subulate apex where the anther is attached. The leaves are pinnately 5-foliate or trifoliate. The petioles are broadly winged, 40 to 75 by 18 to 35 mm., narrowly obovate or elliptical, usually rounded at the tip and bluntly pointed at the base. The segments of the rachis are 35 to 65 by 15 to 25 mm., usually elliptical, bluntly pointed at both ends but more rounded (sometimes rather broadly rounded) at the tip. The leaflets, 55 to 125 by 15 to 50 mm., are broadly lanceolate, narrowed from the middle to the long, cuneate base and into an acute or subacute tip, with strongly marked serrations. (See fig. 7.) The terminal leaflet is often much larger than the adjacent lateral leaflets, sometimes one-third longer, usually from one-fourth to one-eighth longer. The spines, 12 to 30 mm. long, are usually paired in the axils of the leaves.

FIG. 6.—*Citropsis Schweinfurthii:* Cluster of flowers, showing stamens arranged to form a staminal tube. From a plant growing in greenhouse of the Department of Agriculture, grown from seed from Budongo Forest, Uganda, Africa. (C. P. B. No. 2902.) Natural size.

Citropsis Schweinfurthii differs from all its congeners in having a short, thick style (shorter than any other species except *C. gabunensis*, which has very small flowers, with a slender style) and slender, broadly lanceolate leaflets, narrowing from the middle into a long, cuneate acute base.

Citropsis gabunensis (Engler), n. comb.

Limonia gabunensis Engler, 1895, *in* Notizbl. K. Bot. Gartens u. Mus. Berlin, Bd. 1, p. 28.
(?) *Limonia Lecourtiana* De Wild., 1904, *in* Ann. Mus. du Congo, Bot. s. 5, v. 1, p. 159–160, pl. 50.
Illus., De Wild., op. cit., pl. 50.

The following specimens have been consulted: **French Congo** (Gabun).—SOYAUX (No. 105), July 25, 1880, Sibanga Farm, Munda. (Dahlem Herbarium,[1] Kew Herbarium; Muséum, Paris, Herbarium). KLAINE (No. 2260), July and October, 1901,

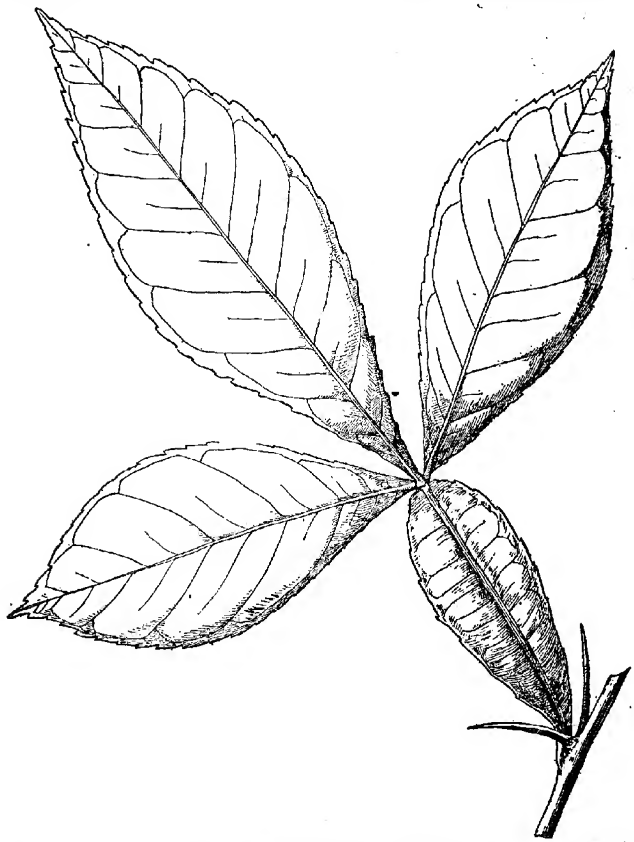

FIG. 7.—*Citropsis Schweinfurthii:* A trifoliate leaf from the type specimen, showing double spines in the axils and pronounced serrations of the leaflets toward the tips (Schweinfurth No. 3656); in National Herbarium, Washington, D. C. Natural size.

near Libreville (Kew Herbarium; Dahlem Herbarium; Muséum, Paris, Herbarium); (No. 1973), March 10, 1901, May and October, 1902, Libreville (Muséum, Paris, Herbarium); (No. 2924, 2925), June, 1902, Libreville (Muséum, Paris, Herbarium); (No. 3494), May 25, 1904, Libreville (Muséum, Paris, Herbarium). BUTTNER (No. 432),

[1] The specimen with the original label attached is the type.

September, 1884, Sibange Farm (Dahlem Herbarium). Du Bellay (No. 4?), 1864 (Muséum, Paris, Herbarium). Tessmann (No. 874), January 26, 1909. Spanish Guinea (?)—Bebady (?); (No. 194), February 14, 1908, Nkolentagan. (?) Congo.—Gentil (No. 93),[1] May, 1903, Bombaie (Brussels Herbarium). Hendrickx (coll. Gillet, No. 3280) Lumene (Brussels Herbarium). Laurent (No. ?), November 28, 1903, Bombaie (Brussels Herbarium).

Citropsis gabunensis, one of the first four species of Limonia, described from Africa by Engler in 1895, was based on specimens collected by H. Soyaux (No. 105) at Sibanga Farm in the Munda region near Libreville, French Congo (Gabun), on July 25, 1880. Three sheets of this number are preserved in the Dahlem Herbarium, and on them the species is based. The type specimen had a single fruit; the paratypes are sterile. The herbaria of Dahlem, Brussels, Paris, and Kew contain numerous other specimens of this species from northern French Congo and Spanish Guinea. This material represents a wide range of foliar characters and shows all stages of flower and fruit development. All these specimens seem to belong to a single species which is very distinct from any of the others.

The type specimen of *Limonia Lacourtiana* was collected by L. Gentil (No. 93), May, 1893, and is preserved along with Gentil's original label in the herbarium of the botanic garden at Brussels. The leaves are all 5-foliate, and in one case a terminal leaflet has a winged petiole. The leaflets are broadly oval, more or less abruptly narrowed at the base, and caudate at the tip. The young fruits are borne in clusters in the axils of the leaves on pedicels 10 to 12 mm. long. In all of these characters this specimen is indistinguishable from *Citropsis gabunensis*.

A young fruit from this type specimen now preserved in the National Herbarium at Washington, D. C., seems to be seedless, but shows numerous pulp vesicles which contain a whitish granular wax.[2] The original label of M. Gentil says "fruits délicieux," but as the fruits in the type specimen are very small and immature it is obvious that his statement must apply to some other plant, doubtless not belonging to this species. Most of the fruits of the typical *Citropsis gabunensis* examined contain large seeds, often nearly filling the small fruit and leaving very little space for the pulp vesicles, which are crowded and often nearly obliterated by the seeds.

Whether the vesicles of a young seedless fruit of the typical *Citropsis gabunensis* would show the presence of wax remains to be investigated. In the absence of knowledge on this point it seems inadvisable to recognize *Limonia Lacourtiana* as a species distinct from *Citropsis gabunensis*, though future research may possibly prove it to be a good species.

[1] This is the type specimen of *Limonia Lacourtiana*.

[2] Recently, through the kindness of M. Auguste Chevalier and of Rev. J. Gillet, of Kisantu, Congo, abundant material has been received of a species of Citropsis apparently distinct from any hitherto described, the fruits of which are often seedless and contain abundant pulp vesicles filled with a wax, which, when extracted, makes a yellow, fragrant mass much like beeswax in character.

Citropsis gabunensis differs from all its congeners in having very small flowers, with hairy filaments, caudate leaflets, and a nearly dry fruit. The flower buds are only 5 to 6 mm. long and the fully expanded flowers are only 10 to 12 mm. in diameter. The filaments are hairy. The pistil is very short (3½ to 4 mm.) and shows a well-marked, clavate ovary, narrowed gradually toward the base and rounded at the tip, which is clearly delimited from the slender style which ends in the subglobose 4-lobed stigma. (See fig. 4.) The pedicels are very long (sometimes 8 to 12 mm.), often twice as long as the pistil, and appear as branches of a slender peduncle ½ to 2 cm. long.

No other species of Citropsis shows so much variation in the size of the leaves and in the number of leaflets. They may be unifoliate, greatly resembling orange leaves, or they may have 5 to 7 leaflets. Very frequently the leaves are 5-foliate, with the terminal leaflet borne at the end of a winged segment of the rachis. Such stalked terminal leaflets are often seen in trifoliate leaves (see fig. 3) but almost never in 5-foliate leaves of other species of Citropsis. The leaflets are caudate—unlike any of the other species.

Those of compound leaves are from 40 to 115 by 18 to 60 mm., mostly 50 to 100 by 25 to 45. The leaflets of unifoliate leaves are 90 to 150 by 40 to 70 mm. The winged petioles are 15 to 35 by 3 to 15 mm., varying from linear to narrowly obcordate, especially in unifoliate leaves. They are usually broadly rounded at the tip and narrowed gradually toward the base. The rachis segments vary from 20 to 45 by 4 to 10 mm. and usually have the same shape as the winged petioles.

Citropsis mirabilis (Chev.), n. comb.

Limonia mirabilis Chevalier, 1912, *in* Bul. Soc. Bot. France, t. 58, 1911, Mém. 8d, p. 144–145.

The following material has been consulted: Ivory Coast.—CHEVALIER (No. 21609), May 21, 1909, between Sanrou and Quode on the Koue River (Chevalier Herbarium, Paris; National Herbarium, Washington, D. C.).

Chevalier has described *Citropsis mirabilis* in detail, but unfortunately no fruits are known. The leaves are 3- to 5-foliate, with broadly oval or oblong leaflets 90 to 190 by 40 to 100 mm. The petioles are usually elongate elliptical, 60 to 70 by 20 to 30 mm., rather acute at both ends, rarely broadly rounded at the tip. The segments of the rachis are 80 to 70 by 12 to 28 mm., usually narrowly elliptical, rarely broadly rounded at tip. The spines are single, 10 to 28 mm. long, sometimes wanting. The flowers occur in dense many-flowered clusters in the axils of the leaves. The pedicels are well-developed, 5 to 6 mm. long. The buds are linear elliptical, 12 to 14 by 3 mm., the flowers when open are 18 to 24 mm. in diameter, usually 4-merous, but sometimes 5-merous. The pistil is 12 to 14 mm. long, the style 10 to 11 mm. long, very slender, and not appreciably broadened at the base.

Citropsis mirabilis differs from all its congeners in having large flowers with slender styles not much broadened at the base and, in consequence, rather clearly delimited from the tip of the ovary. (See fig. 4.) It somewhat resembles *C. Preussii* in the size and shape of the leaves.

IMPERFECTLY KNOWN SPECIES

Citropsis articulata (Willd.), n. comb.

Citrus articulata Willd., 1826, *in* Spreng., Syst. Veg., v. 3, p. 334.

The following material has been consulted: Gold Coast.—ISERT (No. ?; Willdenow Herbarium No. 14357), June or July, 1786, near Kommang, Akwapim [1] (Dahlem Herbarium). (?) Togo.—BAUMANN (No. 552), 1894–5, on the Koli River near Kame (Dahlem Herbarium).

The specimen in the Willdenow Herbarium at Dahlem, of which a photograph was kindly sent to the writers by Prof. Urban, now shows a single twig, 21 cm. long and 2½ to 4½ mm. in diameter, with 10 or 11 internodes which are mostly 2 to 2½ cm. long, slightly angular, with prominent leaf scars. Only two single spines are preserved, one 8 by 1 mm., the other 14 by 1½ mm. Two petioles are on the sheet: One, still attached, obovate in outline, 52 by 32 mm. tapering gradually into the sharp base 4 to 5 mm. long; the other broadly rounded at tip, 60 by 37 mm. with prominent veins, running nearly at right angles to the midrib, the margin very shallowly undulate crenate. It is evident that the Isert specimen at Dahlem was more complete when Sprengel published Willdenow's description, as the leaves are said to be oblong and the peduncle many-flowered. Probably only a single terminal leaflet was originally present. The many-flowered peduncle seems also to have fallen off since Willdenow's time, as none can now be seen on the photograph.

To this species has been doubtfully referred a specimen from Togoland collected by E. Baumann (No. 552), on May 16, 1895, on the Koli River near Kame, probably not very remote from the locality where Isert's type was collected. The Baumann specimen has 3- to 5-foliate leaves, with petioles varying somewhat in size and shape, 35 by 13, 60 by 25, 32 by 50, 40 by 18, or 30 by 20 mm. Curiously enough, the terminal portion of the twig, including the last five or six internodes, has lost its leaves except one obovate petiole. It has three single spines and in general resembles in a striking manner Isert's specimen, upon which Willdenow based his species. Another curious coincidence is in the presence of the terminal leaflet of an originally trifoliate leaf from which the two lateral leaflets have fallen. It was probably from such an apparently unifoliate leaf originally present on Isert's specimen that

[1] Isert found this plant in the mountains some 50 to 75 km. north of Accra and says of it: "Je vis une nouvelle espèce de citroniers, avec des feuilles articulées." (Isert, P. E. Voyages en Guinée et dans les Iles Caraïbes en Amérique, p. 255–256. Paris, 1793. A reprint of the original edition, Reise nach Guinea . . . 1788, appears in Allgemeine Geschichte der neuesten Reisen und Entdeckungen, v. 1.)

Willdenow described the leaves as oblong. This Baumann specimen shows an axillary inflorescence comprising some 6 to 8 flowers with slender ovaries (10 to 11 mm.) and very slender styles somewhat like *Citropsis mirabilis*. The leaves of the Baumann specimen have more broadly winged petioles than the *C. mirabilis*, and doubtless because of this it was referred in the Dahlem collection to *C. Preussii*, from which it differs in the distinctly shorter, more slender style, the narrow smaller leaflets, and the broadly rounded tips of the winged petioles and segments of the rachis. The flowers in the Baumann specimen are more densely clustered and shorter pediceled than in *C. mirabilis*.

It is to be hoped that more complete material collected by Isert may be found in the Copenhagen Herbarium which will permit the affinities of this species, the first of the group to be discovered, to be determined with exactitude.

Besides the foregoing, there remain two more African species of Limonia which undoubtedly belong to Citropsis, but which can not as yet be satisfactorily placed because of insufficient material. These are *Limonia Poggei*, var. *latialata* De Wild., doubtless distinct from *L. Poggei*, and *Limonia Demeusei* De Wild. Both have been described and beautifully figured.[1]

In addition to the material cited, specimens are to be found in the various European herbaria and in the National Herbarium at Washington, D. C., which it has been impossible to place, owing to the lack of flowers or fruits. This additional material represents collections, principally from Congo, by Auguste Chevalier, Ém. and M. Laurent, Demeuse, L. Gentil, and others.

POSSIBLE USES OF THE AFRICAN CHERRY ORANGES

The bringing to light of a new genus belonging to the true-orange group opens up a new field for the plant breeder, especially as some of the species are said to bear delicious fruits in abundance.

The unusually large compound leaves—often with five leaflets, each one of them larger than any ordinary orange leaf—give several of the species of Citropsis a distinct advantage over any other member of the true orange group. Large leaves are an outward and visible sign of an active assimilating system, and it must not be forgotten that over three-fourths of the dry substance of a plant is made up of starch, sugar, oil, flavoring matter, and other substances manufactured in the leaves, and a species with large leaves is equipped with the first essential for rapid growth and for developing sweet fruits of high flavor.

[1] Wildeman, Émile de. Études sur la Flore du Bas- et du Moyen-Congo. *In* Ann. Mus. du Congo, Bot. s. 5, v. 1, p. 159–160, pl. 51, 53. 1904.
Limonia Poggei, var. latialata. *In* Gard. Chron., s. 3, v. 53, no. 1380, p. 378, fig. 159, June 7, 1913.

GRAFTING OF CITROPSIS

Experiments conducted under the directions of the authors in the greenhouses of the Department of Agriculture at Washington, D. C., show that *Citropsis Schweinfurthii* can be grafted readily and that it will grow rapidly and vigorously on sweet orange, sour orange, grapefruit, and lemon stocks. It can also be grafted on the tabog (*Chaetospermum glutinosa*) and the wood-apple (*Feronia elephantum*), two stocks on which species of Citrus graft readily. However, it does not grow as vigorously on these stocks as on Citrus. The very rapid growth of Citropsis when grafted on Citrus (see Pl. XLIX) is an added and striking proof of the close affinity of these two genera. Additional experiments in budding and grafting on other genera related to Citrus are now under way.

In view of the considerable botanical differences between Citrus and Citropsis, it is probable that the latter will show immunity to diseases and adaptations to soil and climatic conditions not possessed by the stocks upon which citrous fruits are commonly grafted. Experiments conducted by the authors have already indicated that *Citropsis Schweinfurthii* is well adapted to poor, sandy soils ("high pine lands") in Florida. Every new stock well adapted to Citrus gives the grower and the pathologist a new tool in the work of perfecting the culture of citrous fruits and in preventing the ravages of diseases by using stocks which are immune. The scarcity of material of the African cherry oranges has hitherto prevented any extensive experiments in the use of this new stock, but grapefruit and oranges have both been budded successfully on Citropsis stocks in the greenhouse at Washington and out of doors in Florida.

HYBRIDIZATION OF CITROPSIS

The fact that there are a number of closely allied yet distinct species of Citropsis native to the forests of tropical Africa is an advantage to the plant breeder in furnishing material for the improvement of the African cherry oranges by hybridization. Whether the waxy-fruited species will yield edible hybrids when crossed with the juicy-fruited species can only be told by experiment.

So far, the scarcity of flowers of the African cherry oranges has prevented any decisive test as to whether they can be crossed with species of Citrus or not. This much can be said, that flowers of the common lime, *Citrus aurantifolia* (Christm.) Swing., pollinated with *Citropsis Schweinfurthii* set fruit and produced seed. Only a few seed were secured and none of them gave rise to a hybrid, but this is not uncommon in Citrus. The fact that the pollen of Citropsis was able to cause the development of seeds is a very hopeful sign that hybrids will be secured from pollinations in the course of the breeding experiments now being carried on by using the pollen of Citropsis on as many species of Citrus as possible.

That hybrids of the common citrous fruits with the African cherry oranges would be promising table fruits is rendered probable by the fact that both Citrus and Citropsis have species which in a wild state yield fruits beautiful to the eye, fragrant, and delicious to the taste.

Because of their beautiful foliage, their very fragrant, large white flowers, much resembling those of the orange or lime, and their abundant, though small, fruits, borne in tufts like cherries, the African cherry oranges are of unusual promise for ornamentals and for hedge plants in subtropical regions.

The fact that the true relationships of so large and so striking a group of plants, ranging clear across equatorial Africa, could remain misunderstood by botanists for so long a time, is another proof of the rich harvest of new material which awaits the attention of the plant breeder as soon as a critical taxonomic study of the wild relatives of our principal cultivated plants makes it available for his use.

PLATE XLIX. *Citropsis Schweinfurthii* grafted on grapefruit stock (*Citrus decumana*), showing vigorous growth made in 2½ years. Plant grown in greenhouse, Department of Agriculture, Washington, D. C., from seed from Budongo Forest, Uganda, Africa. (C. P. B. No. 2902.) One-sixth natural size.

PRELIMINARY AND MINOR PAPERS

WINTER SPRAYING WITH SOLUTIONS OF NITRATE OF SODA[1]

By W. S. Ballard, *Pathologist, Fruit-Disease Investigations, Bureau of Plant Industry*, and W. H. Volck, *County Horticultural Commissioner of Santa Cruz County, California.*

INTRODUCTION

Recently several investigators[2] have reported results in shortening the rest period of a number of woody plants by immersing the dormant shoots in weak nutrient solutions or by injecting solutions of alcohol, ether, and various acids into the twigs. These experiments have been conducted in the laboratory with short cuttings of the plants. The effect of such treatment has been to force the dormant buds out several days ahead of the normal opening period.

During the last two years the writers have obtained similar and additional results on a much larger scale by spraying dormant fruit trees with strong solutions of certain commercial fertilizers, especially nitrate of soda. Since these experiments have been conducted on the entire trees in the orchard, it has been possible to observe the effects throughout the whole season. The investigations have not yet been carried far enough to permit drawing any conclusions regarding the physiologic action of such spraying, but because of its practical value these preliminary results seem deserving of attention at this time.

EXPERIMENTS IN 1912

In the course of the investigations of the writers on the control of apple powdery mildew in the Pajaro Valley, Cal., it became evident that the general vigor of the tree and the thriftiness of the foliage growth had much to do with the success of the summer spraying treatment for the control of the mildew, and after a number of experiments in applying plant-food materials to the foliage in the form of summer sprays, and after seeing that certain crude-oil emulsions used as dormant sprays had a marked effect in stimulating an increased vigor of the trees the following spring, it was decided to try the effect of a strong solution of nitrate of soda as a winter or dormant spray. Caustic potash (potash lye) was also added for the purpose of giving the spray an insecticide value. The mixture was prepared according to the following formula:

Nitrate of soda	50 pounds.
Caustic potash	7 pounds.
Water	50 gallons.

The experiment was conducted in a Yellow Bellflower apple orchard owned by Mr. O. D. Stoesser, of Watsonville, Cal. This orchard is

[1] These investigations were conducted in cooperation between the Office of Fruit-Disease Investigations of the Bureau of Plant Industry and the Office of the County Horticultural Commissioner of Santa Cruz County, located at Watsonville, Cal. The writers' names appear above in alphabetical order.

[2] See references to literature, p. 444.

situated about 5 miles from the ocean shore and is in a district that is more subject to ocean fogs and trade winds than is the main portion of the Pajaro Valley. It is a common characteristic of the numerous orchards of Yellow Bellflower apples of this particular district that they bloom abundantly, but set only a partial crop. The trees are on a deep sedimentary soil and grow well.

Seven 12-year-old trees were sprayed on February 2, 1912. The application was very thoroughly made, so that all of the small twigs were drenched. About 7 gallons of spray solution were applied to each tree. Adjoining this row on one side was a check row of seven trees which received no winter spraying, and on the other side were several rows of seven trees each which received various applications of crude-oil emulsions and soaps. For the purpose of gaining some idea of the effect of nitrate of soda used as a fertilizer, 50 pounds were applied as a surface dressing to one vigorous tree selected from the row adjoining the nitrate-sprayed row. This fertilizer was later plowed in and washed down by the rains.

EFFECTS ON BLOSSOMING AND ON THE FOLIAGE

Notes taken at the time the trees were coming out in the spring show the following results:

April 7, 1912. Trees in the row sprayed with nitrate of soda and lye are well in bloom, while those in the check row adjoining and in the remainder of the unsprayed orchard are showing only an occasional flower fully opened.

April 14, 1912. The relative advancement of the row sprayed with a solution of nitrate of soda and lye and the check plat is the same as noted on April 7. The nitrate-sprayed trees are nearly in full bloom, whereas comparatively few blossoms have opened on the check plat.

When the check row had reached full bloom, the row sprayed with a solution of nitrate of soda and lye was practically out of bloom.

Thus, the nitrate spraying advanced the blossoming time about two weeks ahead of the normal period. It is characteristic of the Yellow Bellflower variety of apples in the Pajaro Valley that the foliage buds come out early, so that by the time the full-bloom period is reached the trees are showing a considerable amount of young foliage. The nitrate spraying produced a change in this respect. While the flower buds were greatly stimulated in coming out, the foliage buds were not so much affected, and the result was that when the trees sprayed with a solution of nitrate of soda and lye were in full bloom and two weeks in advance of the check trees in that regard, their foliage condition was relatively nearer that of the check. Plate L shows the comparative stages of the nitrate-sprayed and the check trees at that time. A decided contrast will be seen in the relative advancement of the bloom on the tree sprayed with nitrate of soda (Pl. L, fig. 1) as compared with the check tree (Pl. L, fig. 2). This contrast is shown more in detail in Plate LI, in which figure 1 shows a branch from a nitrate-sprayed tree, while figure 2 shows one from a check tree. Both branches were collected on the same day. An examination of the figures in Plate L will show that the advancement of the foliage on the nitrate-sprayed tree is comparatively less marked than that of the bloom. This same condition is shown in detail in Plate LI, in which it will be seen that there is relatively little difference in the advancement of the foliage of the sprayed and unsprayed branches. Later in the spring, however, the effect on foliage growth became more pronounced, and the sprayed trees assumed a more vigorous, green appearance than the check trees. The single tree that received the 50 pounds of nitrate of soda applied to the soil showed no greater vigor than the check trees.

Both the row sprayed with nitrate of soda and the check row received summer sprayings directed toward the control of apple powdery mildew and of codling moth and various other insect pests. While the treatment of the two rows was not the same, there was no essential difference in the results—that is, the crop loss from codling moth and other insect pests did not exceed 1 per cent on either plat and there was no damage to the fruit from summer spraying. It is therefore evident that the difference which showed up in the crop production of the two rows must be attributed to the winter nitrate spraying.

CROP RESULTS

The check row of seven trees, which received no winter spraying but which was properly protected by summer sprayings, produced 8 loose boxes of fruit at picking time. On the other hand, the adjoining row, sprayed in February with the solution of nitrate of soda plus lye, produced a total of a little over 40 boxes. Thus, the winter nitrate spraying increased the crop production to fully five times that of the unsprayed row. Similar adjacent plats, which were winter-sprayed with various crude-oil emulsions and soap sprays, produced crops varying from 5 to 9 boxes per plat. The single tree which received the 50 pounds of nitrate of soda applied as a fertilizer gave no increased production, whereas none of the trees in the nitrate-sprayed row failed to respond.

Regarding the single, heavily fertilized tree, it might be stated that in addition to its showing no increase in production, the tree bloomed no earlier than normal, there was no improvement in the growth and no change in its general appearance throughout the growing season of 1912, and in the spring of 1913 it came out normally and not differently from the other trees in the same row, being one of the trees in a check plat. The tree is still in normal condition and shows no noticeable effect from the heavy fertilizing. The orchard is not irrigated, and the rainfall has been much less than normal during the last two years.

Attention might again be called to the conditions under which these results were obtained—namely, thrifty-growing trees in a deep residual soil and having the characteristic of blooming abundantly each year but setting only a shy crop. Even the 40 boxes produced by the nitrate spraying does not represent the full crop that such trees should bear, but the fourfold increase much more than paid for the cost of spraying, and the possibility remains of still further increasing that production by similar treatment in following years.

EXPERIMENTS IN 1913

The one small experiment on seven trees in 1912 did not furnish sufficient grounds for drawing any general conclusions as to the applicability of winter nitrate spraying, but the striking results obtained opened a wide field of inquiry. For instance, potash lye was added to the solution of nitrate of soda in the experiment of 1912, so the questions arise as to whether the lye was necessary and whether an acid medium would increase or decrease the effect of the nitrate of soda; also, would a weaker nitrate solution prove as effective and would other nitrogen-bearing fertilizer materials, such as lime nitrate, lime cyanamid, and sulphate of ammonia, give similar results? Following along this line it would be interesting to know what effect, if any, the other fertilizer elements,

potash and phosphoric acid, might have when applied as sprays, and finally, what results might be obtained from a similar application of other substances not ordinarily considered as having any particular fertilizer value.

Experiments intended to answer these and a number of other more or less important questions were started in February, 1913, in the same orchard in which the previous year's work was done. Eleven 13-year-old trees were used in each plat. A frost occurred at the time the fruit was setting which ruined the crop and made it impossible to obtain results in crop production. Data were obtained, however, on the effect of the various sprays on the blossoming of the trees in the spring, and the notes taken may be summarized as follows:

The plats sprayed with nitrate of soda at the rate of 1 pound to the gallon came into bloom earlier than the check trees, just as they had done in 1912. This effect was more marked in the cases in which lye was added to the nitrate solution than when the plain water solution was used—that is, the addition of lye in the proportion of 16 pounds of caustic soda in 100 gallons of spray solution increased the action of the nitrate of soda in bringing the trees out earlier. Caustic soda appeared to be just as effective as caustic potash. Nitrate of soda used at the rate of half a pound to the gallon, either with or without the addition of lye, was not nearly so effective as a solution of 1 pound to the gallon. A solution of one-fourth of a pound to the gallon, with lye added, had practically no effect. Nitrate of soda, at the rate of 1 pound to the gallon, to which oxalic acid was added in the proportion of 50 pounds to 125 gallons of solution, produced results similar to nitrate of soda plus lye, so far as the effect of hastening the blooming period is concerned. Lime nitrate, 130 pounds in 100 gallons of water, and lime cyanamid, 92 pounds in 100 gallons of water, stimulated an earlier blooming of the trees, and subsequent experiments will probably put these substances in a class with nitrate of soda. Normal Yellow Bellflower apple blossoms have considerable pink color, and it was interesting to note that when the trees sprayed with the lime cyanamid came into bloom the flowers were nearly white. The effects from sulphate of ammonia were not nearly so marked as those from nitrate of soda. These various nitrogen-bearing fertilizer substances were used in such strengths as to carry relatively the same quantities of nitrogen per gallon. Sulphate of potash had some effect in stimulating an early blooming, but double superphosphate did not. Of a number of other substances tried, common salt used at the rate of 68 pounds to 100 gallons of water produced a distinct effect.

It will be borne in mind that the above remarks apply simply to the effects of the various sprays in causing an earlier blooming of the trees, but since this early blooming was a striking characteristic of the nitrate-sprayed trees of 1912, which showed a fourfold increase in production, it seems permissible to conclude that this effect on the fruit buds is some criterion of what might have been expected in the way of crop increase had not the fruit been lost by frost.

The row of seven trees used in the nitrate experiment of 1912 was left unsprayed this last season for the purpose of determining whether the nitrate effect would continue to the second year. It was noticed that the fruit buds on these trees were particularly large and plump, and somewhat unexpectedly at blossoming time these trees came into bloom several days ahead of the check rows. The bloom came out very uniformly all over the trees, whereas ordinarily it is considerably delayed on the wind-

ward side. Also, the individual blossoms were conspicuously larger than those of any other plat, and, so far as could be judged at the time the frost occurred, a good crop was setting all over the trees. Thus, it appears that this effect of the nitrate of soda had continued over to the second year.

At present, all things considered, the best results have been obtained by using a mixture made up as follows:

Nitrate of soda	200 pounds.
Caustic soda	25 pounds.
Water	200 gallons.

In preparing this solution the required quantity of water was placed in the spray tank and the agitator started. When the water was in motion, the required weight of nitrate of soda was added gradually. Any large lumps were first broken up into pieces about the size of hen's eggs. The caustic soda was then added, and in about 15 minutes from the time the preparation was begun the mixture was ready for applying.

The trees were very thoroughly sprayed on all sides, so that all of the small twigs were drenched. The best results so far obtained have come from the spraying applied about the 1st of February. Of course, weather conditions must be taken into consideration. A rain immediately following the application will wash much of the material off of the trees, and it is probable that at least a week of clear weather should follow the spraying, in order to insure good results.

In all of this work on spraying a solution of nitrate of soda on the trees a considerable quantity fell to the ground, and the question will be raised as to whether the various effects observed have not been simply the result of the fertilizer action of the nitrate on the soil. About 7 gallons of the solution were used in spraying each tree, and if the whole of this had gone on the ground it would have amounted to about 7 pounds of nitrate of soda per tree. The single tree in 1912 that had the 50 pounds of nitrate applied to the soil therefore received over seven times the total quantity applied to any single sprayed tree. As has been previously stated, this single, excessively fertilized tree bloomed no earlier than normal, produced no increased crop, and showed no improvement in general vigor and appearance; whereas, none of the trees in the sprayed plat failed to respond in all of these particulars. Of course, this single tree test in the application of nitrate to the soil is too small an experiment to permit concluding positively that the effects that we have reported from the spraying experiments are of an entirely different nature and belong in a different category from those produced by the ordinary soil application of nitrate. A careful consideration of the results of ordinary orchard practice in fertilizing seems to make it plain that there is no similarity between them and the results from spraying. For instance, in the usual practice of applying nitrate of soda as a fertilizer to apple orchards in the region of Watsonville, Cal., a winter or early spring application does not force the bloom out 10 days or 2 weeks ahead of the normal opening period and has had no measurable effect in increasing the set of fruit that same year. The fact that the addition of caustic soda or oxalic acid to the nitrate spray augments these various effects further emphasizes the difference between the results from spraying and the ordinary results from the application of fertilizer. Caustic-soda solution alone applied as a spray has no effect on the time of blooming or the crop production.

EXPERIMENTS OF GROWERS IN 1913

YELLOW BELLFLOWER APPLES

During the past season a number of growers made more or less extensive tests of the spraying with nitrate of soda. An aggregate of several hundred acres of Yellow Bellflower apples was sprayed with nitrate of soda plus caustic soda, but practically all of this acreage was in the same district in which the writers' experiments were conducted, so the crop was lost by frost. It was noticeable during the past summer, however, that the foliage in such orchards as received very thorough winter nitrate sprayings had a better appearance than in years past, due apparently to the effect of the nitrate. One orchard, that of MacDonald & Sons, is located in a district that practically escaped frost damage, and the results obtained indicated a marked crop increase in consequence of the spraying. The entire orchard, with the exception of a few trees, was sprayed with various combinations of nitrate of soda and lye, and, while no exact data on the production of the unsprayed trees as compared with the rest of the orchard was obtained, the amount of fruit on the trees indicated that the spraying had produced a marked increase. This conclusion was more reliably substantiated by comparing the total orchard production this year with that of previous years.

SWEET CHERRIES

Mr. A. W. Taite, of Watsonville, sprayed portions of two blocks of Napoleon (Royal Ann) cherries with nitrate of soda, 1 pound to the gallon, to which caustic soda was added at the rate of 25 pounds to 200 gallons. Unsprayed rows adjoining the sprayed ones were left in each block. In one case the sprayed trees were distinctly advanced over the check trees in coming into bloom. In both cases there was an increase in the foliage growth and a consequent improvement in the appearance of the trees. No effect on crop production could be noticed, though it is possible that treatment in successive years may bring such results.

PEARS

For our observations on pears the writers are indebted chiefly to Mr. George Reed, of San Jose, who carried out extensive tests in the orchards of the J. Z. & G. H. Anderson Fruit Co. The spraying was done about the 1st of February and the following notes are taken largely from Mr. Reed's observations:

CLAIRGEAU.—Four rows of about 40 trees each were sprayed with commercial lime-sulphur solution (33° Baumé) diluted 1 to 9. Adjoining these were four rows sprayed with lime-sulphur solution diluted 1 to 9 and to which was added nitrate of soda at the rate of 1 pound to the gallon of the diluted spray. The rows sprayed with the combined solution of nitrate of soda and lime-sulphur came into bloom about a week ahead of those that received the lime-sulphur solution alone. The development of the fruit on these nitrate-lime-sulphur solution rows continued to show an advancement of about a week throughout half the growing season, and at picking time the fruit was greener and hung on better than that of the plain lime-sulphur-solution rows. Both plats bore a full crop, so there was no opportunity for observing any effect on production. The Clairgeau variety blooms early, and the further advancement due to nitrate spraying might result in frost injury in some localities. The fruit ordinarily has a habit of dropping off during the latter part of the growing season. This difficulty, however, was largely eliminated on the nitrate-sprayed rows.

COMICE.—The major portion of the block was sprayed with a plain water solution of nitrate of soda at the rate of 1 pound to the gallon. A small portion was sprayed with commercial lime-sulphur solution, diluted 1 to 9, with nitrate of soda added at the rate of 1 pound to the gallon of diluted spray. Through a misunderstanding the men doing the spraying left no check rows in this block, so that crop data couln not be obtained. However, Mr. Reed's exact knowledge of the previous productiod of this block as a whole indicates that the marked increased production this last season was more than probably due to the nitrate spraying. The Comice is a relatively shy bearer, and a valuable pear commercially, so that any increased production that could be obtained by nitrate spraying would be much appreciated by the grower. One portion of the block that regularly produces less than the remainder gave a good crop this year, and it appeared that the addition of the lime-sulphur solution augmented the effect of the nitrate of soda just as the addition of lye has done in the experiments of the writers.

GLOUT MORCEAU.—A block of Glout Morceau pears was sprayed with the combination of lime-sulphur solution, diluted 1 to 9, plus nitrate of soda 1 pound to the gallon of diluted spray. This block had never produced a full crop, and while no unsprayed checks were left, the increased production this year would appear to be due to the nitrate spraying.

WINTER NELIS.—A block of Winter Nelis pears was sprayed with a solution of nitrate of soda 1 pound to the gallon of water. No lime-sulphur solution was added in this case. No check rows were left, and a frost destroyed a large percentage of the fruit after it had set. However, at that time the trees were carrying the largest crop they had ever produced, and again it would appear that the nitrate spraying had had a beneficial effect. The trees came into bloom about 10 days ahead of normal opening period.

DISCUSSION OF RESULTS AND SUMMARY

It is not the writers' intention to convey the impression that dormant spraying with nitrate solutions will solve the problem of shy bearing of fruit trees nor offer a more advisable method of applying nitrogen fertilizer. The purpose of this paper is simply to present the results as they now stand.

It is evident that, at least under certain conditions, some varieties of apples and pears that are more or less self-sterile may have their crop production materially increased by dormant spraying with solutions of nitrate of soda plus lye. The combination of a solution of nitrate of soda and lime-sulphur is apparently capable of bringing similar results.

Actual quantitative data on increased production from spraying with a solution of nitrate of soda are available from only one source, that of the first experiment on Yellow Bellflower apples in 1912. No production records were obtainable from the various tests made by growers during the season of 1913, but the one test on Yellow Bellflower apples and several others on pears indicate that such an increase had undoubtedly been brought about. It is considered that the growers' knowledge of the crops of the previous years as compared with that of this year furnishes a basis for conclusions that are at least corroborative.

That nitrate spraying of dormant trees will bring about an earlier blooming of certain varieties of fruit is a satisfactorily established fact, which has been demonstrated on Yellow Bellflower apples at Watsonville, Cal., and on various varieties of pears at San Jose, San Juan, and Suisun, Cal., during the past season. How generally this statement will apply to other varieties of apples and pears and in other localities remains to be determined. Results on stone fruits have not been as striking as those on pears and apples, but it is possible that stronger solutions, earlier spraying, or a repetition of the spraying in successive years may bring about such results.

The greater danger of injury from frost that might result from forcing trees into bloom earlier than normal would have to be taken into consideration in making practical use of nitrate spraying in winter.

Aside from the effect on crop production, there has also been a very noticeable improvement in the color, abundance, and vigor of the foliage, and it seems possible that nitrate spraying of dormant trees may be a valuable supplement to the ordinary fertilizer practices in obtaining quick results in orchards suffering from lack of nitrogen.

The writers will make no attempt at present to explain the peculiar effect of nitrate of soda in increasing the production of more or less self-sterile varieties of fruits, or in improving foliage growth. The similarity between the writers' results in forcing dormant buds by winter nitrate spraying and the results obtained by other investigators by treating cuttings with various weak solutions has been mentioned. In experiments of the writers, however, a more or less lasting effect on the vigor of the foliage and also some valuable results in increasing crop production have been obtained. It furthermore appears that the effects obtained by spraying with a solution of nitrate of soda may continue over to the second year, as shown by the original plat of 1912, which was left unsprayed in the winter of 1913.

The effects of the nitrate spraying seem to be proportional to the strength of the solution employed and the thoroughness with which it is applied. The addition of caustic soda materially increases this action.

LITERATURE

The following is a short list of some of the more recent literature on forcing the buds of dormant cuttings of woody plants.

JESENKO, FRANZ.
Einige neue Verfahren die Ruheperiode der Holzgewächse abzukürzen. Ber. Deut. Bot. Gesell., Bd. 29, Heft 5, p. 273–284, pl. 12, 1911; Bd. 30, Heft 2, p. 81–93, pl. 3, 1912.

———
Über das Austreiben im Sommer entblätterter Bäume und Sträucher. Ber. Deut. Bot. Gesell., Bd. 30, Heft 4, p. 226–232, pl. 9. 1912.

LAKON, GEORG.
Die Beeinflussung der Winterruhe der Holzgewächse durch die Nährsalze. Ein neues Frühtreibeverfahren. Ztschr. f. Bot., Jahrg. 4, Heft 8, p. 561–582. 1912.

WEBER, F.
Über die Abkürzung der Ruheperiode der Holzgewächse durch Verletzung der Knospen, beziehungsweise Injektion derselben mit Wasser. Sitzber. K. Akad. Wiss. [Vienna], Math. Naturw. Kl., Bd. 120, Abt. 1, Heft 3, p. 179–194, pl. 1. 1911.

PLATE L. Fig. 1.—Yellow Bellflower apple tree in full bloom on April 16, 1912, showing effect of spraying with a solution of nitrate of soda plus caustic potash on February 2 previous.

Fig. 2.—Unsprayed check tree for comparison with figure 1.

The illustrations are from photographs taken on the same day.

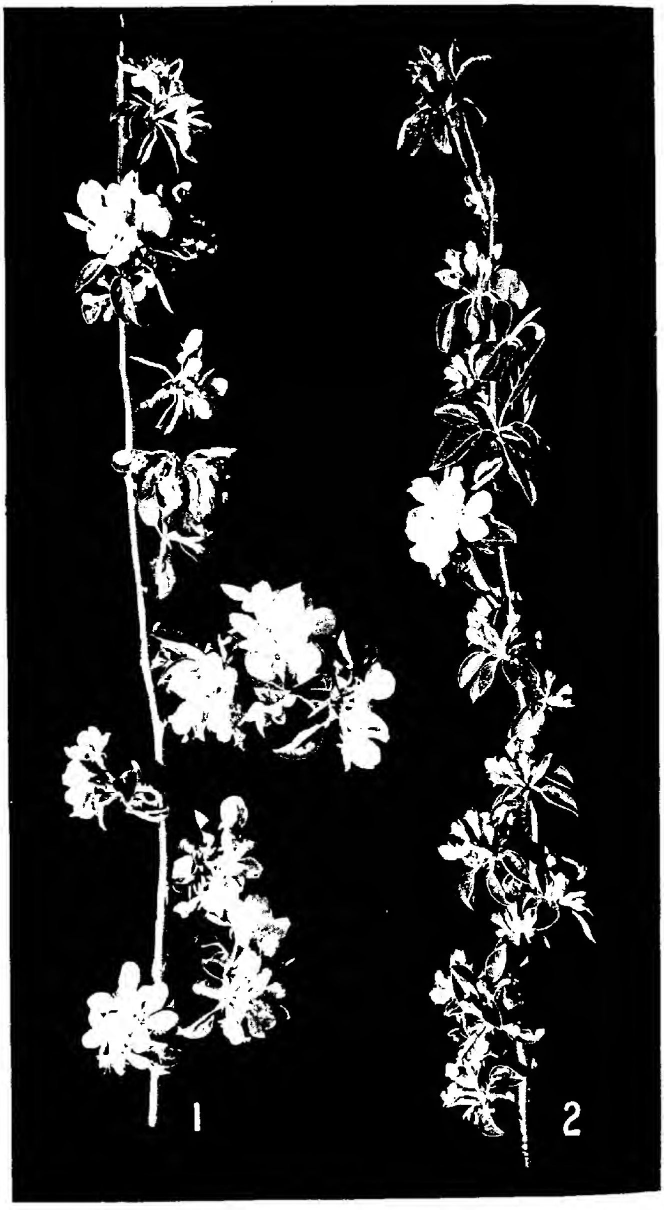
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PLATE LI. Fig. 1.—A branch from a Yellow Bellflower tree in full bloom on April 10, 1913, showing the effect of spraying with a solution of nitrate of soda plus caustic soda on February 3 previous.

Fig. 2.—A branch from an unsprayed check tree for comparison with figure 1.

The illustrations are from photographs taken on the same day.

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